Air Repair

A QUARTERLY JOURNAL DEVOTED TO AIR PURIFICATION

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AIR POLLUTION CONTROL ASSOCIATION
4400 FIFTH AVENUE
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Vol. 4, No. 1

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Entered Air Pollution Control work in Los Angeles County in April, 1948 as Senior Inspector, Assistant Director and in July, 1949 became the Director.

Mr. Larson has authored many technical papers concerned with air pollution, which have received international attention in engineering and scientific circles.

The Editor welcomes writers interested in air pollution problems and encourages them to use the pages of this journal for the expression of their opinions. But neither he nor the Association assumes responsibility for the validity of the opinions expressed herein.

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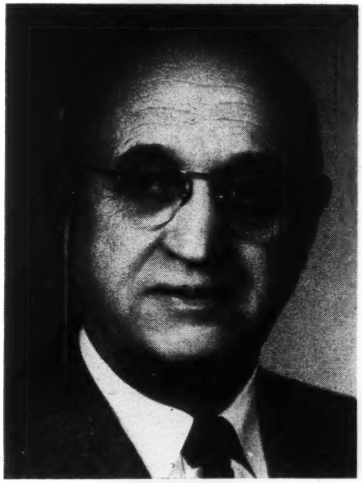

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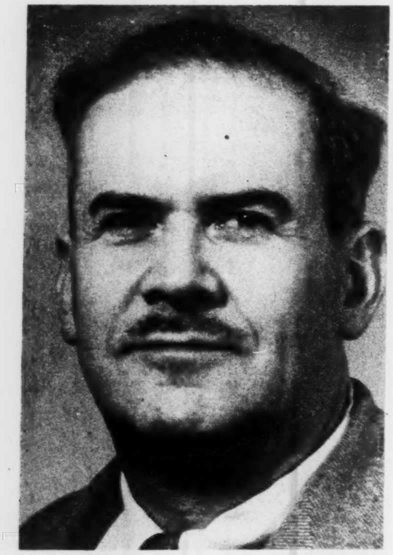

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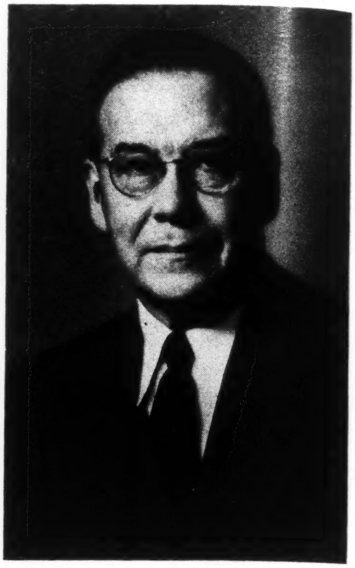

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Thermal Precipitation in Air Pollution Studies

By Mendel T. Gordon and Clyde Orr, Jr.
Georgia Institute of Technology
Atlanta, Ga.

With the increasing interest in aerosols in the size ranges below 10 μ both for air pollution evaluation purposes and for accurate process material balance calculations, a sampling device capable of high collection efficiencies would appear to be of general interest. Such a device can be made utilizing the phenomenon of thermal repulsion.

Tyndall[1] in 1870 was the first to note the dustfree space which surrounds a heated wire that is suspended in a dusty atmosphere. On the basis of Tyndall's assumption that the dustfree space was due to the volatilization and destruction of particles in the neighborhood of a heated wire, contemporaries, stated that Tyndall's experiments proved that a very large proportion of the suspended particles in the London atmosphere consisted of water and other volatile liquid or solid matter. Shortly thereafter, however, Lord Rayleigh[2] showed that only very small temperature differences are necessary for the observation of the dustfree space thus refuting the idea that volatilization is responsible for this effect.

The first sampling apparatus, utilizing thermal repulsion, was designed and constructed by J. Aitken[3]. In the course of studying the mechanism by which dust particles are deposited in the lungs, he became interested in thermal repulsion. Aitken discovered that if a stream of air containing dust particles was made to flow slowly between a hot wire and a cool surface which intersects the dustfree space, the suspended matter would collect on the cool surface. Aitken's first device consisted of a horizontal, heated wire placed between two vertical glass plates. The aerosol flowed upward past the wire by natural convection, and the dust particles were precipitated on the glass plates. The Mine Safety Appliances Co., Pittsburgh, Pa., is currently marketing a device based on this same design made by C. F. Cassella and Co., Ltd., London. Several types of similar design are also being made by Jos. B. Ficklen, III, of Pasadena, California. In these devices the suspended matter is deposited on an electron-microscope screen or a glass microscope cover slip. The maximum allowable flow rate varies between about 5 and 20 cc/min. in these devices.

Another device designed by Aitken utilizing thermal repulsion consisted of two concentric tubes. The dust-laden air was drawn between the inner and outer tubes; the outer tube was heated by a gas flame or by steam. From his experiments using this device as a filter, Aitken concluded that it was possible to obtain complete precipitation of the particles providing proper flow rates and thermal gradients were used.

In 1920, the U. S. Army Chemical Warfare Service[4] experimented with a concentric-tube thermal filter, thirty inches long, and found that with a temperature difference of 80°F. and a flow rate of 550 cc/min. no particles were visible in the effluent gas stream. However, this device was abandoned because of its high power consumption and low flow rate.

More recently, a slightly modified concentric-tube precipitator was developed by Bredl and Grieve[5] for the collection of suspended matter in the flue gases. This device consisted of a tapered, heated inner tube and a readily removable outer tube of aluminum foil upon which the particulate matter deposited. The aerosol entered the precipitation chamber at the large end where only the particles most readily precipitated were deposited. As the aerosol progressed into the chamber, the space between the hot and cold surfaces diminished and the materials less affected by thermal repulsion were deposited. Bredl and Grieve found that the fly ash in

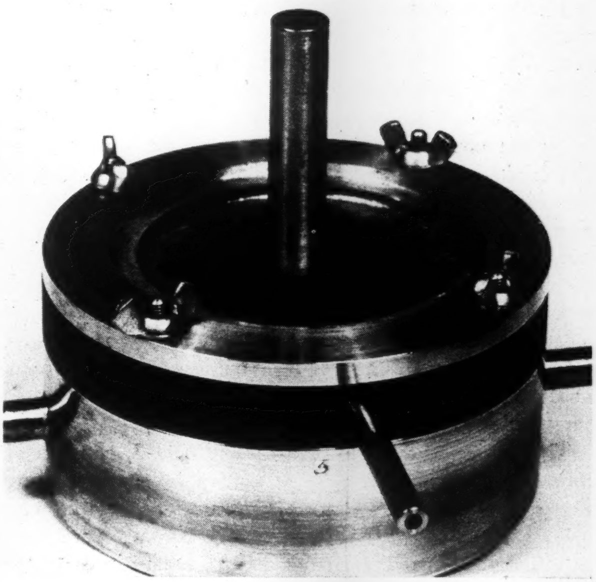

Fig. 1. Thermal precipitator designed at Georgia Tech.

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[1] Tyndall, J., "On Dust and Disease." *Proc. Roy. Inst. 6,* 3 (187).

[2] Rayleigh, Lord, "On the Dark Plane Which is Formed Over a Heated Wire in Dusty Air." *Proc. Roy. Soc. (London) 34,* 414 (1882).

[3] Aitken, J., "On Formation of Small Clear Spaces in Dusty Air." *Trans. Roy. Soc. Ed. 32,* 239 (1884).

[4] Bancroft, W. D., "Thermal Filters." *Jour. Phys. Chem. 24,* 421 (1920).

[5] Bredl, J., and Grieve, T. W., "A Thermal Precipitator for Gravimetric Estimation of Solid Particles in Flue Gases." *Jour. Sci. Inst.* 28, 21 (1951).

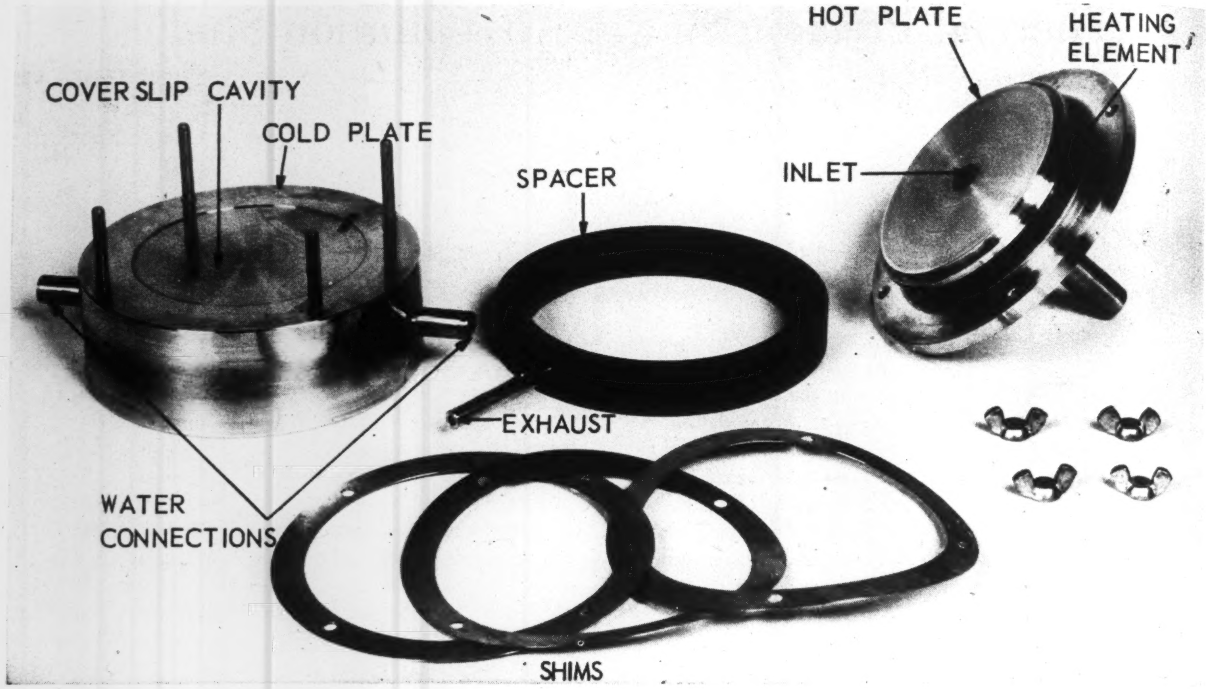

Fig. 2. The components of the Georgia Tech thermal precipitator.

their flue gases was deposited near the entrance and the carbon near the exit. This device was capable of handling flows up to 150 cc/min.

Jos. B. Ficklen, III, makes a device which could be considered as a modification of the concentric-tube design. In this device the aerosol flows between a heated plate and a cooled microscope slide. The flow rate in this device is reported to be about 650 cc/min.

In the course of an investigation relating to aerobacteriology at the Engineering Experiment Station, Georgia Tech, the possibility of utilizing thermal repulsion was examined. With the main purpose being a sampler in which an environment as favorable to the survival of viable organisms as possible would be maintained, several samplers were built. The sampler[6] found to be most applicable to aerosol sampling situations encountered in the Micromeritics and of Bio-engineering Laboratories at the Georgia Tech Engineering Experiment Station is herewith described.

The device, shown in Figures 1, 2 and 3, consists of three main parts: the base or cold plate, an insulating spacer and the upper plate assembly or hot plate. The base is a hollow disk through which cooling water can be circulated. A circular cavity, three inches in diameter and 0.008 inch in depth, is machined in the upper surface of the base for positioning a glass cover slip of these same dimensions. The insulating spacer separates the two surfaces and serves to form a manifold-like space with the upper plate assembly, so that the aerosol will flow evenly outward in all directions from the inlet. A tube in the side of the spacer acts as an exhaust. The hot-plate of upper-plate assembly consists of a commercial disk heating element soldered to a machined brass plate. When in place, the underside of the outer edge of this piece makes an airtight seal with the insulating spacer. A central tube acts as the inlet to the sampler. The temperature of the hot surface can be controlled with a variable transformer. The spacing between the hot and cold surfaces can be varied by using brass shims of different thicknesses between the insulating spacer and the upper-plate assembly.

In practice, the aerosol enters the sampler through the

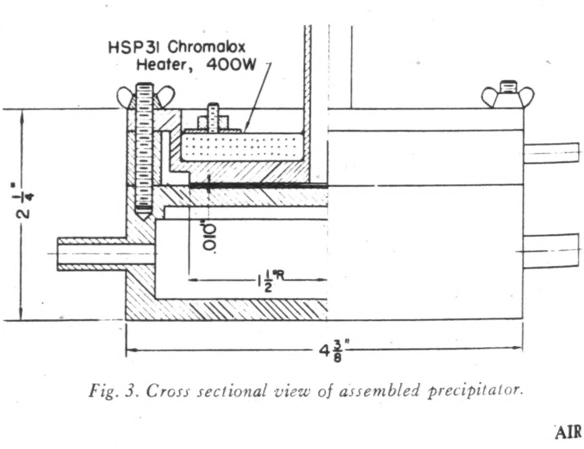

Fig. 3. Cross sectional view of assembled precipitator.

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[6] Kethley, T. W., Gordon, M. T., and Orr, Clyde, Jr., "A Thermal Precipitator for Aerobacteriology." *Science 116*, 368 (1952).

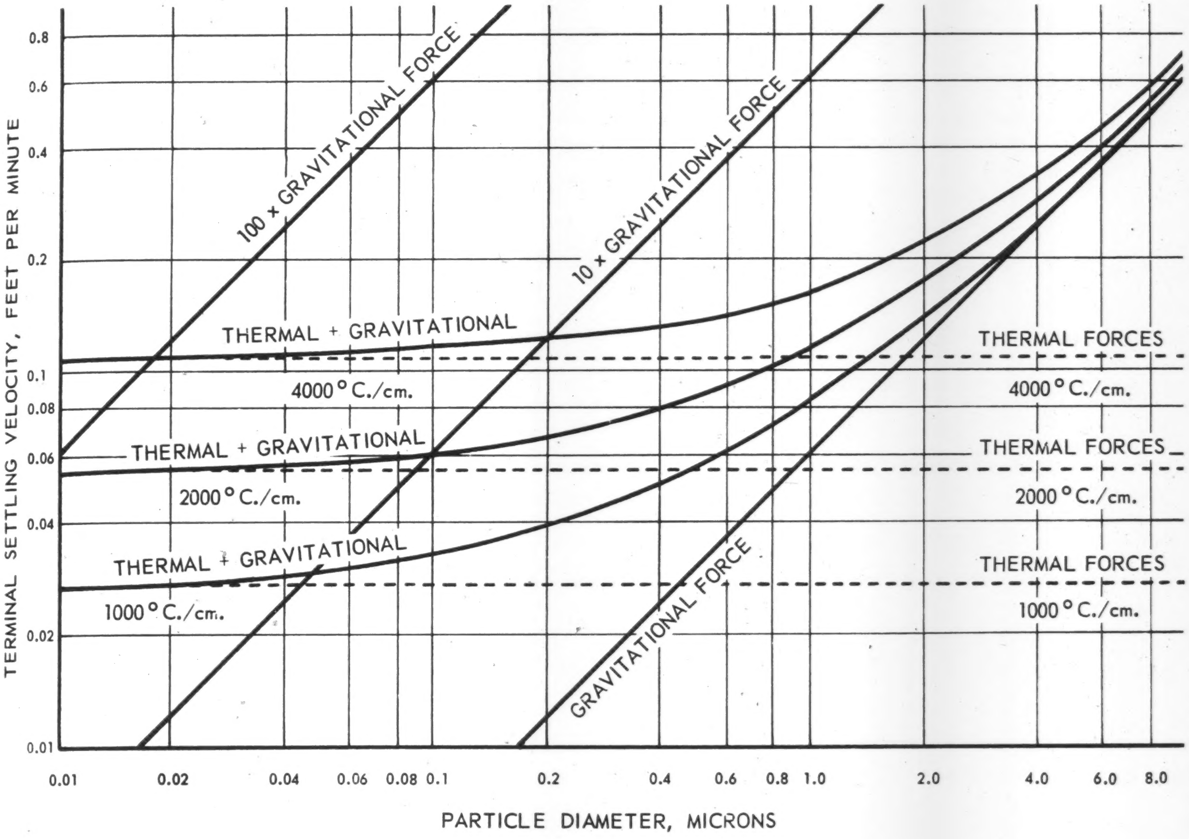

Fig. 4. Terminal settling velocity of water droplets in gravitational and thermal fields.

central tube and flows radially outward between the heated and cooled surfaces which are 0.010 inch apart into the plenum formed by the upper-plate assembly and the insulating spacer and out through the exhaust tube. The deposit of aerosol material on the cold plate appears as an annular ring whose outer diameter is a function of the operating conditions and the physical properties of the aerosol.

The above design makes possible the optical microscopic examination of all kinds of airborne particles. Electron-microscope examinations are done by using a replica technique or by placing several electron-microscope screens, upon which a silicon monoxide film has been deposited, in the sampler.

When collecting bacteria and liquid aerosols, the temperature gradient is limited to less than 80°C. per 0.010 inch to prevent thermal damage and evaporation of the collected material. For non-volatile solids such as clays, MgO smokes, etc., much higher gradients can be used. At the aforementioned 8,000° C/inch, the flow rate used is 300cc/min.; at higher gradients proportionately higher flows can be used.

Saxton and Ranz[7] measured the magnitude of thermal force and confirmed Epstein's[8] equation for describing it, hence it is now possible to predict the characteristics of thermal precipitators of various designs. A plot of the terminal velocity of water droplets resulting from both gravitational and thermal forces versus particle diameter is presented in Figure 4.

The path of a particle in a precipitator of a given geometry can be predicted by making a force balance on the particle using the equations for thermal force, gravitational force and viscous drag. The equation which results from this force balance relates aerosol flow rate, sampler dimensions and maximum particle penetration with particle density, particle diameter, particle thermal conductivity, physical properties of the gas and thermal gradient. For the precipitator described this equation is

(1)

$$\frac{q}{\pi z\,(z + 2r_o)} = \frac{D_p\,(\rho_s - \rho_g)\,g}{18\mu_g} + \frac{3}{2}\,\frac{\mu}{\rho T}\,\frac{k_g}{2k_g + k_p}\,\frac{\Delta T}{x}$$

where q = volume rate of flow

z = length of deposit, i.e., z = (radius of deposit — radius of inlet opening)

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[7] Saxton, R. L., and Ranz, W. E., "Thermal Force on an Aerosol Particle in a Temperature Gradient." *Jour. Appl. Phys. 23,* 917 (1952).

[8] Epstein, P. *Z. Physik 54,* 537 (1929).

r_o = radius of inlet opening
ρ_s = density of aerosol material
ρ_g = density of gas
g = gravitational acceleration
μ_g = viscosity of gas
T = absolute temperature of the gas
k_g = thermal conductivity of the gas
k_p = thermal conductivity of the aerosol particle
ΔT = temperature difference between hot plate and cold plate
x = distance between hot plate and cold plate

The right side of equation (1) is the expression for the critical velocity of a particle in a thermal precipitator of a design such that the aerosol is constrained to flow between two plane surfaces and normal to thermal and gravitational fields acting in the same direction. The left side of equation (1) was obtained from the particle trajectory as shown below.

Figure 5 shows a diagrammatic sketch of the thermal precipitator. If the velocity of the particle is resolved into its vectors, where V is its vertical component of velocity and U is its horizontal component of velocity,

$$U = \frac{Q}{\pi (r_o + z)\, x},$$

or

$$\frac{dz}{dt} = \frac{Q}{\pi (r_o + z)\, x},$$

$$(r_o + z)\, dz = \frac{Q}{\pi x}\, dt.$$

Integrating gives

$$\int_o^{z} (r_o + z)\, dz = \frac{Q}{\pi x} \int_o^{t} dt,$$

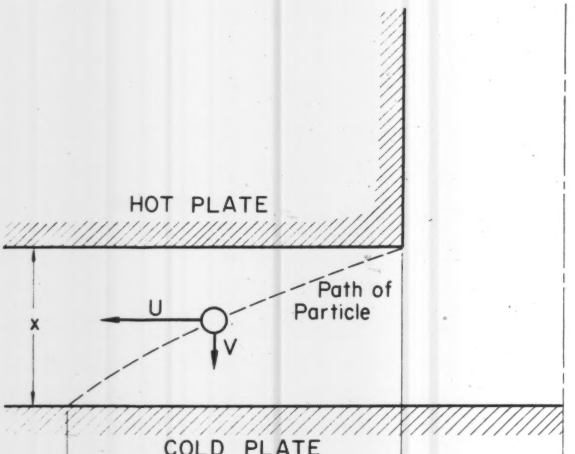

Fig. 5. Diagrammatic sketch of the thermal precipitator.

and solving for t gives

$$t = \frac{\pi x z\,(z + 2r_o)}{Q}.$$

But

$$V = \frac{x}{t'},$$

or

$$t' = \frac{x}{V}.$$

The particle traverses distance x in the same time it traverses distance z, therefore

$$V = \frac{Q}{\pi z\,(z + 2r_o)}. \tag{2}$$

Of course, all particles do not enter the thermal gradient at the location indicated in Figure 5; therefore, the particles are classified according to size in such a manner that a radial traverse of the deposit shows a continuous decrease in the maximum size present with increasing distance from the inner edge of the deposit. Similar expressions can be derived for precipitators of other geometries. The utility of equation (1) is exemplified by the fact that an enlarged thermal precipitator with a capacity of about 5 l./min. was designed and constructed using this equation to obtain the dimensions of the heated disk. This precipitator was used for the routine examination of bacterial, latex and clay aerosols, and as a source of small quantities of particle free air, as well as for the examination of smokes and liquid aerosols. In addition to the many uses which are obvious to those familiar with the aerosol field, there are several other possible applications which can be suggested.

In the field of biologicals, a thermal precipitator such as the one described here could be used to check the sterility of the atmospheres in plants producing pharmaceuticals and antibiotics, especially in the production of antibiotics where it is absolutely necessary to have air free of contaminating molds and fungi.

The constantly increasing industrial activity in the use of radioactive materials gives rise to problems of particulate wastes which cannot be treated in the same way as inert dusts, where the main objective is to reduce the loading below the nuisance level. With radioactive airborne wastes, concentrations well below that which would be considered a nuisance could still be a health hazard. The device described herein could be used to sample for radioactive airborne particles using the technique of autoradiography[9]. In this technique, the glass cover slip containing the deposit is placed on a piece of photographic film for a short time. When the film is developed, a radioactive particle will appear as a number of tracks radiating from a central point. This technique also permits a determination of particle size.

(Concluded on page 39)

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[9] Leary, J. A., "Particle-Size Determination in Radioactive Aerosols by Radioautograph." *Anal. Chem. 23*, 850 (1951).

A Low-Cost Sampler For Measurement of Low Concentration of Hydrogen Sulfide

By J. DEANE SENSENBAUGH
and W. C. L. HEMEON
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Mellon Institute
Pittsburgh, Pa.

Hydrogen sulfide is an air pollutant, whose primary nuisance effects are in the slow tarnishing of silverware, and in the blackening of house paints containing lead pigments. The suddenly occurring paint blackening episodes attract the most attention and occasion greatest citizen resentment.

Exterior paints containing titanium pigments are not affected by hydrogen sulfide, and there is an increasing trend toward the use of this kind of paint in industrial districts.

The concentration of hydrogen sulfide required to produce a noticeable blackening of lead paint in a short time interval of a few hours is not known although it appears entirely probable that the lowest significant concentrations are below the limit of odor perception, a scale of which is shown in the following table:

Scale of Odor Perception for Hydrogen Sulfide

Concentration, PPM	*Odor Perception*
0.02	Non-detectable
0.1	Minimum detectable
0.8	Readily perceptible though weak
5	Odor of moderate intensity
25	Strong

These data are based upon initial impressions; on short exposure the olfactory nerves become fatigued, and then these figures would not apply.

Except for accidental emission of massive quantities of the gas, no question of health hazard is ever involved in practice since the concentrations required to produce any physiological effects are very much higher than are ever encountered outdoors. (Exposures to concentrations higher than 20 ppm for a minimum of 6 to 8 hours are necessary to cause irritation of the eyes, the earliest "toxic" effect.)

Experience strongly suggests that the paint blackening episode may require four coincident circumstances, namely, (1) conditions of high humidity at, or close to, 100 per cent, (2) the weather condition of strong or shallow inversion, (3) significant wind direction, and (4) sufficient emission of hydrogen sulfide to result in concentrations of a certain magnitude, perhaps in the vicinity of 0.1 ppm. The necessity for coincidence of all conditions would account for the relatively infrequent occurrence of such episodes.

When such an episode does occur, it immediately raises the questions: Where did the gas originate in general, and where in particular? Was there some unusually large emission of hydrogen sulfide from some operation? Because the occurrences are infrequent and develop in a short period of a few hours, usually overnight, it is impossible to establish the facts later by air analysis. This indicates the need for a simple, low cost automatic sampling instrument so that numbers of them, strategically located, could provide a continuous record of atmospheric conditions to give the desired information at a time when it is needed.

The A.I.S.I. Hydrogen Sulfide Sampler

The sampling instrument developed for these purposes is a modification of the A.I.S.I. Automatic Smoke Sampler developed in our laboratory.(1) In the smoke sampler air is drawn at a rate of approximately ¼ cu. ft. per minute through a 1 inch circle on filter paper tape by means of a slow-motion reciprocating diaphragm pump. A simple timing arrangement shifts the paper tape into a new position after any desired time interval.

The low cost and simplicity of that instrument are desirable features also in a gas sampler, and it was accordingly adapted for measurement of hydrogen sulfide. This required two supplementary features.

(a) Removal of the black solids prevalent in ordinary air from the air sample by efficient filtration while permitting passage of the hydrogen sulfide gas content; and

(b) Preparation of an impregnated filter paper tape so that some intense color change would occur that is proportional to the concentration of hydrogen sulfide or to the power of the gas content to blacken certain surfaces, e.g. lead house paints and silverware.

For removal of the solid contaminants from the air stream, a CC-6 filter, enclosed in a cylindrical cartridge, is employed. To avoid excessive pressure drop, a large area of 25-30 square inches is provided.

To prevent contamination of the paper in the area adjacent to the sampling circle, the entire front, including the paper on the supply roll and the wind-up roll, is enclosed. In order to avoid diffusion of contaminated air into this enclosure, the air discharged from the pump, purified by passage through a soda lime tube, is discharged into the enclosure, whence it leaks outward through cracks

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1. Hemeon, W. C. L., Haines, G. F., Jr., and Ide, Harold M., "Determination of Haze and Smoke Concentrations by Filter Paper Samplers," AIR REPAIR, *3*, 22 (August, 1953).

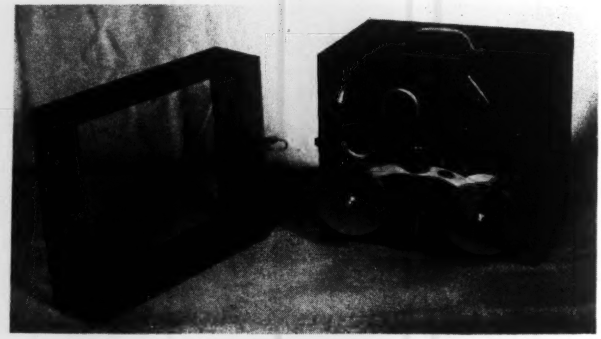

Fig. 1. The hydrogen sulfide sampler with front casing removed. (Courtesy Research Appliance Co.)

and orifices, thus maintaining the enclosure interior under positive pressure. The latest model of this instrument is illustrated in Figure 1.

Impregnated Tape for Sampler

The best formulation for the filter paper, selected after extensive tests, involves impregnation of Whatman No. 4 filter paper tape with a lead acetate-glycerine combination. Lead acetate paper has been used for many years for the qualitative detection of hydrogen sulfide. For quantitative estimation of H_2S concentrations, both acidic (2) and basic (3.4) lead acetate formulations have been recommended as filter paper impregnants, and both types were tried. The alkaline lead acetate papers were unsatisfactory from a stability standpoint. The use of acetic acid in the formulation, as recommended by British workers (2), was investigated, but the final formulation did not include acetic acid. The sampling paper finally adopted was prepared by impregnation with a solution containing 5 per cent lead acetate and 5 per cent glycerine, as described below.

It was found that this formulation gives a good gradation of spot intensity with varying H_2S concentration and stability of the stains is superior to other formulations. It also maintains its sensitivity on aging of the paper before use, and the calibration curves are nearly linear and reasonably reproducible.

The impregnated paper is prepared in the following manner. Whatman No. 4 filter paper tape and a strip of surgical gauze are rolled up together, so that a layer of gauze lies between each layer of tape on the roll. This roll is soaked for 15-20 hours in the impregnating solution. The tape is then dried by slowly unrolling it in front of a bank of infra-red lamps in a drying cabinet.

Blackening of the lead content of the paper by the formation of black lead sulfide occurs when the quantity of hydrogen sulfide passing through the sample circle exceeds a certain quantity (about 0.0005 cc.).

Stability of Spots

The stability of spots formed on paper prepared by the above procedure was checked by taking light transmission readings at intervals up to 8 days after formation of the spots. The papers used in these tests were kept rolled up except when taking readings. Slight fluctuations were observed in the light transmission readings, but for spots with initial transmission values up to 70 per cent, these fluctuations rarely exceeded 2-3 per cent. Spots with initial values of 70-75 per cent gained only about 5 per cent in light transmission in 6-8 days. For lighter spots in the range of 75-90 per cent light transmission, there was no evidence of large scale fading when the initial readings could be made within a few hours after formation of the spot. When such samples were stored as rolls, some fading occurred within four days. In some cases the indicated nominal concentration was halved.

It is concluded from these data that significant fading may occur in extremely faint spots (transmission greater than 90 per cent), but this can minimized by recording results each day.

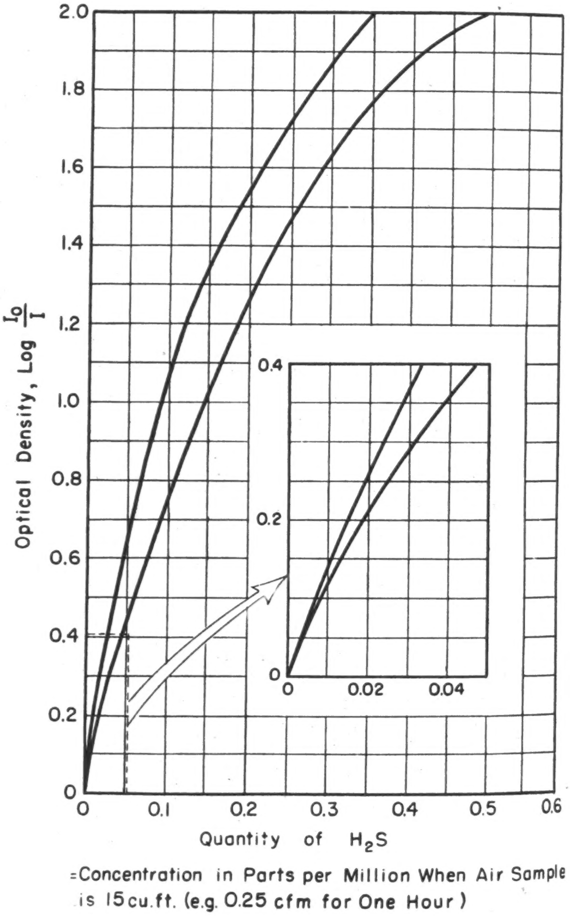

Fig. 2. Calibration curve for estimation of quantity of hydrogen sulfide from intensity of stain.

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2. "Methods for the Detection of Toxic Gases in Industry. Hydrogen Sulfide." Leaflet No. 1, Dept. of Sci. and Indus. Res., H. M. Stationery Office, London, 1937.
3. Truesdale, E. C.. "Sensitivity of Various Tests for Traces of Hydrogen Sulfide," Ind. Eng. Chem., Anal. Ed.. 2. 299 (1930).
4. Moses, Douglas V., and Jilk, Lawrence T., U. S. Pat. 2,232,622.

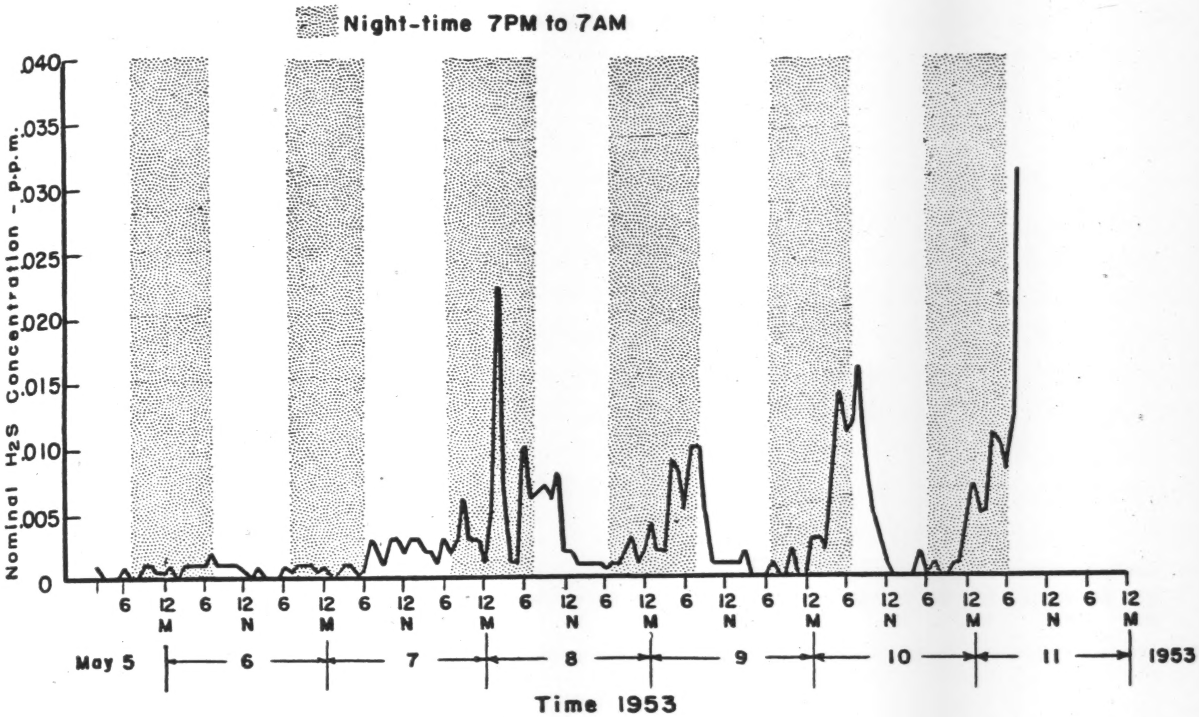

Fig. 3. Record of "silver tarnishing concentrations" of hydrogen sulfide during a random 5 day period in the Oakland section of Pittsburgh.

Evaluation of Concentrations

The intensity of the spots obtained with this sampler is converted into convenient numerical quantities by measuring the intensity of light transmitted through the spot relative to the blank portion of the paper. Apparatus for making this measurement is the same as that used for evaluating the samples obtained with the Automatic Smoke Sampler.(1)

Optical density is obtained from the measured light transmission by the formula:

$$\text{Optical Density} = \log \frac{I_o}{I} = \log \frac{1}{T} = \log \frac{100}{\%T}$$

An estimate of H_2S concentrations can be made by reference to the curves shown in Figure 2. It may be seen that there is not an exact correlation between H_2S concentration and optical density. The curves shown here represent the concentration limits actually observed experimentally, but it is possible that these limits might occasionally be exceeded.

The data shown here were obtained with the A.I.S.I. sampler operating at 0.25 cfm, adjusted to provide separate samples once an hour. Under these conditions, concentrations as low as 1 part per billion parts of air (0.001 ppm) are readily indicated. The extreme dilution represented by this concentration can be visualized by noting that such a concentration would occur by mixing only 1 cc. of hydrogen sulfide in a room 50 ft. by 50 ft. by 16 ft. high.

Typical Hydrogen Sulfide Concentrations

At the time of this writing, the sampler has been in nearly continuous operation for about eight months, sampling the outdoor atmosphere at our laboratory. During this period a total of 3138 samples were taken, some of one-hour and some of two-hours duration. The concentration ranges in which these samples fell are given in the following table:

Range (ppm)	*No. of Samples*
less than 0.005	2974
0.005-0.009	122
0.010-0.019	33
0.020-0.029	6
more than 0.030	3
	3138

In the group of samples with concentrations less than 0.005 ppm are included 1084 samples where no detectable concentration of H_2S was found. The higher concentration may occur in a single isolated sample or as a concentration peak several hours long, as shown in the record of several days' operation plotted in Figure 3. Most of the concentrations above 0.010 ppm. occurred in narrow peaks one to three hours long, but one broad peak of about ten

(Concluded on page 25)

An Automatic Impinger For Air Sampling

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Introduction

Since it is becoming increasingly apparent that a very large number of samples are required for a reasonably accurate evaluation of the effects of gaseous contaminants on a community, it must be recognized that manual sampling cannot meet the requirements of an air pollution study. The simplest breakdown of the weather factors which might be expected to affect the concentration of a given contaminant would require 8 wind directions, 3 wind velocity classifications, and 2 classifications for atmospheric stability or a total of at least 48 variables. Conclusions derived from a small number of samples are therefor applicable only to the time of sample collection. The recognized "diurnal variations" show that samples collected only during daylight will often lead to erroneous conclusions. When there are multiple sources for a given contaminant, calculations based on emission rates may become very complicated, and several sampling stations may be necessary to determine the contribution of each source to the area in question. From the standpoint of practicability, automatic sampling instruments provide almost the only means of making quantitative air pollution studies. Practical automatic sampling instruments are not available for the study of many common air contaminants.

Requirements for air sampling equipment have been outlined by Brown and Schrenk (1), and the application of such equipment to outside sampling further defined by Ingram and Dieringer (2). These requirements include the following:

1. The sampling instrument should be capable of collecting a large number of samples without excessive labor requirements.
2. It should be inexpensive enough so that several instruments can be used simultaneously.
3. The sampling method should be versatile enough to allow specific determinations in the presence of various interfering compounds.
4. The volume of sample should be large enough to allow a reasonable sensitivity based on known or suspected information on permissible concentrations.
5. Collected samples must be adaptable to rapid and accurate analysis.
6. Samples should be short enough to allow correlation with changing weather conditions.
7. Provision should be made to relate concentrations to time.
8. For some work, samples should be adaptable to the determination of several different contaminants.

Some of the major air pollution problems common to industrial areas include: sulfur dioxide, hydrogen fluoride, hydrofluosilicic acid, hydrogen sulfide, hydrogen chloride, sulfuric acid, ammonia, and chlorine. In most areas these compounds will not be found as single contaminants, but in combination with each other. Although the effects of combinations of contaminants may sometimes be cumulative, the type and severity of damage may vary greatly from one compound to another, and the sources will usually be different. It is therefor of considerable value to be able to analyze for each compound separately.

One of the first automatic instruments to conform to most of the above specifications was described by Thomas and Cross (3), in 1928. Although this equipment was designed primarily for the collection of sulfur dioxide in a standard iodine solution, it could have been adapted to the collection of other compounds. Two simple scrubbers which operated alternately were filled and emptied and the air flow controlled by a rather complicated system of cam-operated valves. The samples thus collected were discharged into separate containers placed in a turntable below the scrubbers and were taken to the laboratory for analysis. In 1929, Thomas and Abersold (4), modified this instrument by the addition of conductivity cells located in the scrubbers and connected to a conductivity recorder. This made the analysis as well as the collection automatic, but restricted the determination to the measurement of ionizing compounds so that it was specific for sulfur dioxide only when other ionizing substances were absent. In the above list of common air contaminants, only one is non-ionizing. In 1943, Thomas and coworkers (5), made further modifications aimed at simplification, and discussed the use of the instrument for the determination of hydrogen sulfide, chlorinated hydrocarbons, carbon disulfide and other materials by the addition of a combustion device. The major change in the basic instrument involved the substitution of a six port stopcock for the cam-operated valves in the original instrument. No mention is made of the collection of indi-

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1. Brown, C. E. and Schrenk, H. H.: Standard Methods for Measuring Extent of Atmospheric Pollution. U. S. Bur. of Mines Information Circular, 7210 (May 1942).
2. Ingram, William T. and Dieringer, Lawrence F.: Air Sampling Instrumentation, Methods. Ind. Hyg. Quart., 14: 2, 121 (June 1953).
3. Thomas, M. D. and Cross, Robert J.: Automatic Apparatus for the Determination of Small Concentrations of Sulfur Dioxide in Air. Ind. & Eng. Chem., Anal. Ed., 20: 6, 645 (June 1928).
4. Thomas, M. D., and Abersold, John F.: Automatic Apparatus for the Determination of Small Concentrations of Sulfur Dioxide in Air, II. Ind. & Eng. Chem., Anal. Ed. 1: 1, 14 (Jan. 1929).
5. Thomas, M. D. et al. Automatic Apparatus for Determination of Small Concentrations of Sulfur Dioxide in Air. Ind. & Eng. Chem., Anal. Ed., 15: 4, 287 (April 1943).

vidual samples for laboratory analysis. In spite of the efforts at simplification, the instrument was still somewhat complicated as indicated by the fact that the multiple port stopcock had some 26 connections. In 1953, Thomas (6), described still another modification consisting of a single relatively simple scrubber containing a conductivity cell and with the liquid and air flows controlled by 2 cams, 2 or 3 synchronous motors, 2-threeway stopcocks, 1 solenoid, 3 microswitches, a constant leveling device and an automatic pipette. Although this instrument was described for the analysis of sulfur dioxide, the statement is made that "electrolytic conductivity—is not specific for any particular compound."

During the past few years 3 continuously recording analysers for gas sampling have been made commercially available: the Thomas Autometer, the Davis Continuous Analyser, and the Titrilog. The first two scrub the air in continuous absorbers, and record the conductivity of the scrubbing liquid. The Davis instrument has a combustion device which can be used for the determination of hydrogen sulfide, and certain organic compounds, and Thomas described a similar device for his instrument. The Titrilog records the quantity of reducing agents in the sampled air. A portable model of the Titrilog is available, but portability of the others is limited by size and weight.

Although the use of recording instruments provide a continuous record with a short time lag, and a minimum of labor, the fact that they are able to measure only one characteristic of the air contaminants is a decided disadvantage: they are unable to differentiate between contaminants which have the measured physical or chemical characteristic in common. For example, the conductivity method could not be applied to the specific determination of any acid gas unless other ionizing compounds were absent, and the oxidation reduction method could not be applied to the determination of hydrogen sulfide in the presence of sulfur dioxide. Another disadvantage is the cost of recording equipment which in many instances would discourage the use of several simultaneous sampling stations.

Operation of the Automatic Impinger

Although it was recognized that it was probably not possible to build an instrument which would be ideal in all respects, it was felt that practical improvements over available instruments could be made. The most promising ideas were derived from the original instrument described by Thomas (3), and through valuable suggestions by him. Essentially, the Automatic Impinger is a simplification of the cumulative analysers of Thomas. A photograph of one of the completed instruments is shown in Figure 1, and a diagrammatic sketch is shown in Figure 2.

The desired collecting liquid is placed in reservoir 1, stopcock 2 closed and the reservoir inverted so that the stopcock extends into the constant leveling funnel 3. When the three-way stopcock 4 has been rotated by the synchronous motor 6 so that the upper two legs are connected by the stopcock slot, the scrubbing liquid seeks its own level in the impinger 5. When the stopcock 4 has closed, the cam 7 rotated by motor 6 engages the microswitch 8 which turns on the suction pump 9 causing the sample to be drawn through the impinger 5. At the end of the desired sampling period, the cam disengages the micro-

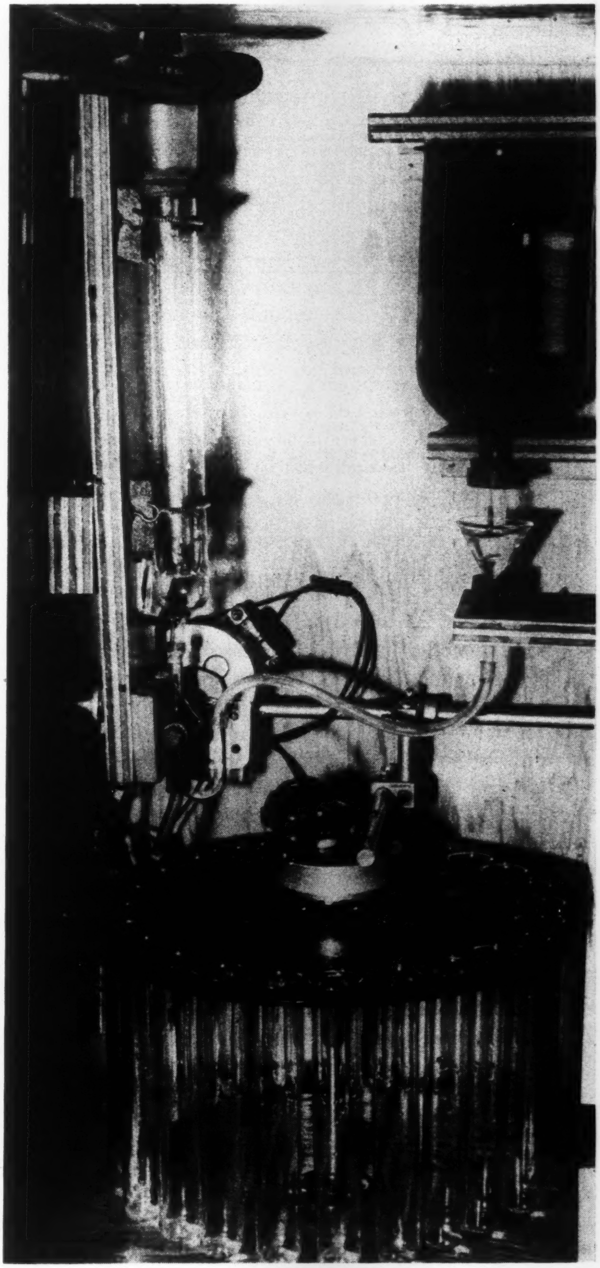

Fig. 1. Automatic Impinger

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6. Thomas, M. D.: Proposed Method for the Continuous Analysis and Automatic Recording of the Sulfur Dioxide Content of the Atmosphere. Report to ASTM Committee D-22. (1953).

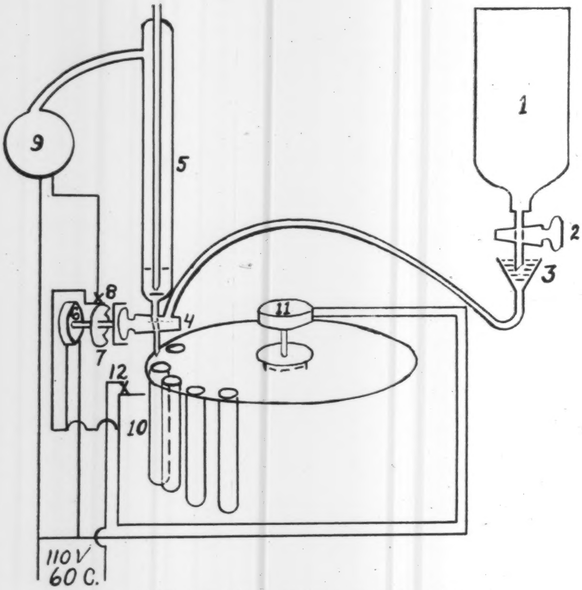

Fig. 2. Diagrammatic sketch of automatic impinger.

switch 8 so that the source of suction is turned off. When the stopcock 4 has turned to the proper position the collected sample is discharged into one of the collecting tubes which is brought into position by the turntable operated by the synchronous motor 11. The cycle is repeated 24 times and the instrument is turned off by a pin at the edge of the turntable which breaks the current in the microswitch 12 discontinuing the sampling.

Collection Efficiency

Since the collecting device conforms to the standard impinger, considerable data applicable to its use is available in the literature (2, 7, 8, 9). In order to provide additional information, the collection efficiency for sulfur dioxide was determined using the acid-hydrogen peroxide solution proposed by Thomas, and also a glycerine-sodium hydroxide solution with analysis by addition of iodine and backtitration with sodium thiosulfate. Concentrations of sulfur dioxide were set up by aspirating air through acid solutions of standard sodium sulfite, and determining the residual sulfite after aspiration. In both series of experiments, 95% or more of the sulfur dioxide was recovered in the impinger for sampling periods of 20 to 30 minutes at an air flow rate of 28.4 liters per minute at about 25° C. The sulfur dioxide concentration was between 0.1 to 1.0 parts per million. Comparative results were obtained by taking simultaneous manual samples of outside air using an alkaline solution of iodine and KI (9). The Automatic Impinger was also checked by manual simultaneous sampling using the same solution for both methods of sampling. It was concluded that the Automatic Impinger has a collection efficiency for sulfur dioxide which is comparable to the standard impinger and which is satisfactory for outside sampling. Other users of the Automatic Impingers have reported that simultaneous results were nearly identical to those obtained with the Thomas Autometer and the Titrilog.

Due to the difficulty of maintaining known concentrations of hydrogen fluoride, the absolute efficiency of collection was not determined. When unknown concentrations of this gas were sampled by three impingers in series at air flow rates of about 25 liters per minute at 25° C. for 15 to 20 minutes, 91% of the total fluorides were recovered in the first impinger. There is little reason to believe that the efficiency would not be above 90%.

Measurement of Air and Liquid Flow Rates

The accuracy of any automatic sampling instrument utilizing the scrubbing principle is dependent on a constant air flow. The variation in resistance of commercially available, manually operated impingers is great enough so that the impinger itself does not provide a standard orifice unless individually calibrated. This objection has been overcome in the Automatic Impinger in two ways: the orifice is made of precision tubing, and since the same impinger is used for all samples, the resistance at a given flow rate remains constant. When the instruments were operated with oiled pumps, it was found that there was some fluctuation in the pump capacity from day to day. An automatic bleeder valve was placed in the line to partially compensate for this fluctuation. Later oil-free pumps were tested and found to provide constant flow without the use of automatic bleeders. Although the resistance of the impinger could be controlled within close limits, it was found that vacuum gages were not always correct, and it was advisable to calibrate flow rates against the vacuum gage to be used with the instrument. Calibration should be made with a volume or flowmeter which introduces low resistance into the system as compared to the total resistance of the system. The error introduced by a flowmeter with a resistance of 3 to 4 inches water gage is approximately 5%.

The intermittent samplers described by Thomas (3, 4, 5), utilized an automatic pipette to measure the solution delivered to the scrubber. Since his original method used a standard solution as a scrubbing medium, a small error in solution measurement would introduce a multiplying error when low concentrations of contaminants were sampled. When a chemical analysis is to be made on the collected sample, reasonable variations in solution volume do not cause any error. When the concentration is to be measured as in the use of conductivity methods, the percentage error will be the same as the percentage variation in solution delivery. This latter error can be eliminated by

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7. Goldman, F. H. et al. Report of Sub-committee on Chemical Methods of Air Analysis. Am. Jour. Public Health Yearbook 30: 2, 92, (Feb. 1940).
8. Clayton, George D., Determination of Atmospheric Contaminants. Paper presented at the Production and Chemical Conference, American Gas Association, New York. (May 1953).
9. Schrenk, H. H. et al. Air Pollution in Donora, Pa. Pub. Health Service Bulletin, No. 306, U. S. Public Health Service, Washington, D. C. (1949).

making the sample to a given volume before measurement of the concentration. The simple constant leveling device used on the Automatic Impinger provides constant solution delivery usually within about 2% and seldom greater than 5% of the desired volume of 50 ml. This error would prevent highly accurate results when standard solutions are used as collecting mediums, but would be satisfactory for other methods. The simplified system eliminates most of the complexities of the instruments described by Thomas.

Length of Cycles and Sampling Time

The frequency of sampling is still probably a matter of debate. While it is true that many very short samples will show more spread between high and low concentrations, there is a practical limit to the number of observations which can be interpreted. It has been observed that concentrations vary relatively slowly at locations fairly remote, and rapidly when close to low sources of emission. Even with fully automatic recording instruments the labor involved in transferring data from charts to forms for tabulation and interpretation of many observations may become burdensome. At the other extreme, it has been proposed that 6 hour periods of integration representing "diurnal fluctuation" may provide considerable information and decrease the work required for analysis. Since it has been observed that wind directions and atmospheric stability may change during one of these periods it is believed that samples should be taken more frequently than four per day. Inspection of weather and sampling data indicates that most variations which may cause sudden changes in concentration of contaminants can be reflected in samples taken at hourly intervals. Although longer cycles could be applied to the Automatic Impinger, shorter cycles would either require a much larger instrument or servicing more than once a day. Instruments in use at the present time collect one sample per hour, and 24 samples without servicing.

In addition to the number of observations which can be handled, the length of sample should be considered. While it is true that one is probably more interested in the relatively high concentrations than in averages, the interpretation of very short peaks requires further study. Shorter observations will result in higher peaks, but damage is probably usually related to time-concentrations, rather than concentration alone. In a previous study, it was found for example that discoloration of lead paint by hydrogen sulfide (10), could be caused by a high concentration in short periods, and also by lower concentrations for longer periods. It is to be noted that the Belgium, Donora, and London episodes occurred when stable atmospheric conditions lasted for several days.

It has been found that most of the required information to be derived from air samples can be obtained when concentrations were integrated for periods of 15 to 20 minutes. Samples of this length usually show peaks of the same general order as shorter samples except at locations close to low level emissions. Average concentrations based on 15 minutes sampling time and collected at hourly intervals, will not be greatly different from results obtained from continuous sampling provided sufficient samples are collected. Since the concentrations will vary from day to day, many short observations taken over a few days will be no more valid than 24 samples of 15 minutes duration taken over the same period.

The first Automatic Impingers were constructed using a conventional 3-way stopcock. Since the stopcock was in the proper position for sampling only about one-third of the time, the maximum sample length was 20 minutes for one hour cycles. By grinding a special stopcock with a slot connecting two adjacent legs rather than opposing legs, it was possible to sample for about 40 minutes, or two-thirds of each cycle. By the use of a double cam, the sampling time can be changed by a simple adjustment from 20 minutes to 40 minutes. Thomas' original sampler was essentially two instruments operated alternately and provided continuous sampling, and a recent modification provided nearly continuous sampling by the use of a combination of motors, cams, microswitches, and solenoids. It is believed that the simplicity of the Automatic Impinger is of value and that failure to provide continuous sampling is not usually a serious drawback.

Practical Analytical Methods Applicable to Automatic Impinger Samples

An outline of suggested methods appears in Table I. The estimated time for analysis is based on a laboratory set up for routine work. Interference from particulate matter and sulfuric acid can be eliminated by attaching a six-inch filter paper adapter to the inlet of the impinger. In several instances it is possible to make several determinations on the same sample. Other methods of analysis may be found in the literature. The method of analysis should be chosen to eliminate expected interfering materials. In certain instances it may be advisable to sample in duplicate using two different methods of collection. Most analyses can be made in the collection tube.

Location of Sample

It was originally thought that sampling points should be located at least 20 feet from any building or other obstruction to prevent the effects of disturbance of air currents. It is now believed that the sampling location for gases is much less critical and that samples may be collected by extending a tube out of a window for a short distance. This eliminates the necessity of weatherproofing equipment. Apparently this applies to fine particulate as well as gaseous matter, since samples collected simultaneously on opposite sides of a building, at fairly high and ground levels showed practically no variation. Samples collected inside a fairly well closed building showed variations and concentrations comparable to

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10. Wilson, William L. et al. The use of Exposure Panels for Measuring Air Pollution. Paper presented to Am. Ind. Hyg. Conference (1952.)

samples collected outside although there was a time lag for the inside samples when a sudden change in concentration occurred outside.

Outline of Suggested Methods for Reporting Results

The first instrument has been in operation two years. Some instruments have collected approximately 10,000 samples with only minor adjustments. Since that time Automatic Impingers have been used by a number of government agencies and industrial concerns for the study of air pollution problems. During this time no reports of unsatisfactory performance have been received. Since the use of the instrument has been confined to specific studies, release of detailed results are not given. However, it is possible to outline methods of interpreting Automatic Impinger results.

Treatment of Data

Unless one may be satisfied with simple average concentrations of contaminants, it is necessary to collect a large number of samples. Usually samples will not be collected at a station unless there is some reason to believe that real or imaginary damage is likely to result or when it is desired to obtain control information for comparison of one area with another. When it is desired to measure damage it is equally important to determine where that damage originates and under what conditions. This type of study can be done only by correlation with weather data. Fortunately it is usually possible to obtain much information of mass air movement from U.S. Weather stations, although this may not always be applicable to local conditions. For a study of this type it is probable that a minimum of 1000 observations may be necessary to give a reasonable evaluation of the conditions at a station. Of the possible weather data which may be used, wind direction is the most important, atmospheric stability second and wind velocity third. To handle data in this manner an organized plan should be followed. It is of value that all weather and sampling information be tabulated on specially prepared sheets with data from all sampling stations and weather stations for a given observation on one line. In order to interpret these data, the use of punch cards will be found almost indispensible. While correlations may be made with hand sort cards, each representing a single observation, much time can be saved by the use of machine sorting. By classifying weather data and analytical results into groups, as many as 12 sets of observations at different stations or contaminants may be handled on one card so that even a very detailed study can be recorded on 24 cards per day.

Correlation with Wind Direction

The first correlation to be made will usually be the determination of average concentration for each wind direction. Due to short horizontal shifts in direction the use of more than 8 direction classifications is usually not justified. When the averages are obtained, the results may be plotted against direction on polar coordinate paper with the average concentration represented by the distance from the center of the paper. If a sufficient number of samples have been collected to be reasonably representative of weather conditions, the resulting diagram will point in the direction of the major sources of

TABLE I

ANALYTICAL METHODS APPLICABLE TO AUTOMATIC IMPINGER SAMPLES

Contaminant	Collecting Solution	Method of Analysis	Reference	Sensitivity P. P. M.	Hours for 24 Analyses
Total acids	$4x10^{-3}$ H_2O_2, $5x10^{-5}$ H_2SO_4	1. Measure conductivity with dipping electrode.	Thomas, (4)	0.005	0.5
		2. Measure pH with meter	Frederick, (11)	0.005	0.5
		3. Titrate with 0.004 N NaOH to Sodium Alizarin Sulfonate. (pH about 5).		0.005	0.5
Sulfur Dioxide	0.1 N NaOH with 5% Glycerin	Acidify, add excess of 0.004 N I_2: backtitrate with 0.004 N sodium thiosulfate.		0.005	0.75
Fluorides	0.1 N NaOH	1. Distill from perchloric acid and silver sulfate, develop color with thorium nitrate, backtitrate standard with sodium fluoride (1 ml. equals 10 micrograms F).	ASTM, (12)	0.001	7
	Water or Acid—H_2O_2 Solution	2. Precipitate sulfates with barium chloride, decant, titrate as above.	Thomas, (13)	0.001	3
Chlorides	0.1 N NaOH	Carefully neutralize to phenolphthalein (colorless) add 1 ml 5% potassium chromate titrate with 0.01 N $AgNO_3$ in porcelain dish.	Mahin, (14)	0.02	2
Ammonia	0.1 N H_2SO_4	Make alkaline in Kjeldahl flask and distill into standard 0.01 N H_2SO_4. Back titrate with 0.004 N NaOH to sodium alizarin sulfonate.		0.02	3 with 8 unit still
Hydrogen Sulfide	$4x10^{-3}$N H_2O_2 $5x10^{-5}$ H_2SO_4	Attach combustion tube to inlet of impinger at 500° C. Analyse for total acids. Duplicate sampling with and without combustion eliminates interference of acid gases.	Thomas, (5)	0.01	0.5

11. Frederick, William. Personal Communication (1953).
12. Proposed Tentative Method of Test for Fluoride Ion in Industrial Water. ASTM Designation D—51T (1951).
13. Thomas, M. D. Personal Communication. (1952).
14. Mahin, Edward G., Quantitative Analysis, second ed. McGraw Hill Book Co. (1919).

the contaminant measured. The validity of the averages so obtained may be checked by comparison with average wind directions taken over long periods and usually obtainable from the U.S. Weather Bureau.

Since the proper location of major sources of contaminants with respect to prevailing wind direction and other weather data promises to be of great practical value in future air pollution control, average concentrations from a given wind direction do not define the contribution of sources in that direction to the pollution of an area represented by a sampling station. For example, a major source will cause pollution only downwind of the source. If a source is located west of a given area and there is seldom an east wind that source may be less important than much smaller sources in other locations. In order to measure the pollution contribution from different wind directions, weighted averages should be considered. These may be obtained by multiplying the average concentration from a given wind direction by the frequency of winds from that direction and expressing the results as a percentage of total time-concentration values. These results may then be plotted on polar coordinate paper as described above. In many instances it will be found that the diagrams will deviate very considerably from those obtained by plotting simple averages against wind direction.

Stability of the Atmosphere

For more detailed studies, a second classification can be made using inversion data as an added factor, in addition to wind direction. The validity of such data will be dependent on ability to define inversions, although qualitative trends are not too difficult to obtain. The importance of considering atmospheric stability is emphasized by the fact that inversions are apparently related to wind direction. It may sometimes be found that a major amount of the pollution of an area as measured by a time-concentration relationship may be coming from a single direction during inversions, even though major sources are to be found in other directions.

Concentrations Above A Given Threshold

Since certain types of damage may result from relatively high concentrations for relatively short periods of time, it may sometimes be of value to consider concentrations above a certain threshold. Although there is inadequate information to accurately define thresholds for many air contaminants, it is known that much of the damage resulting from air pollution is due to relatively short periods of fumigation which may be related to unusual weather conditions, plant breakdowns, failure of control equipment, or intermittent operations which are difficult to predict, or to measure by stock sampling. When there is evidence that damage due to short fumigations has occurred in an area, it is of value to determine the conditions under which abnormally high concentrations occur. In this case, only the concentrations above a certain value are considered, and plotted against weather data as above. At times, the results may bear little relationship to plots of average concentration.

Evaluation of Multiple Sources

In a highly industrialized area, there are frequently many sources of the same contaminant. Although much information may be derived from the determination of emission rates, those results may only be valid for the time of sampling and the interpretation of the data, in terms of the community, may sometimes be difficult. When a given area may be affected by multiple sources, a comparison of those sources may be done by sampling at several stations. One or more stations should be located in the affected area in such a manner that each station would show pollution from various wind directions, in a different manner. In addition other stations should be located, between possible sources, in order to provide controls from one source to another. In this type of study it may be more practical to consider only observations when the concentration is above a known or suspected threshold limit. The frequency of occurrence of high concentrations is plotted on small size polar coordinate paper. These plots are then oriented on a large scale map of the area which may be obtained either through maps or aerial photography. The plots will then point in the direction of the significant sources. Where several sources may be located upwind of the sampling station, additional pinpointing may be done by triangulation of the axes for significant wind directions, and by individual comparison of simultaneous concentrations obtained at the various sampling stations.

Conclusion

A simple instrument for the collection of air samples has been described. The instrument consists of a specially constructed impinger with a mechanism for refilling, collecting a sample, and discharging samples into separate containers for laboratory analysis. Twenty-four hourly samples may be collected automatically without attention.

By careful choice of the absorbing solution and method of analysis, more specific determinations can be made than are possible with several other automatic devices. For example: SO_2 can be determined iodimetrically when other acid gases are present, or conductimetrically when hydrogen sulfide is present.

The instrument is adaptable to any method where a standard impinger can be used except those involving precipitates or where standard solutions are used as absorbents. The sensitivity and range of concentrations to be determined are limited only by the analytical method.

Methods have been described for the analysis of acid gases and fluorides. Suggested methods for interpreting results are given.

Coal Segregation As A Cause of Smoke And Its Correction

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Smoke is often the result of a bad fire on a stoker, which in turn is caused by fuel segregation. If parts of the fire on a stoker receive only fine coal and other parts receive coarse coal, then there will be a variation in the amount of air flowing through various parts of the fuel bed. Those parts of the stoker that receive a deficiency of air will not completely burn the fuel, and, hence, quantities of smoke are produced. Subsequent turbulence in the furnace may burn these unburned gases, but elimination of the causes of incompletely burned gases being formed will help greatly to produce a clean stack.

To illustrate, Figure 1 shows the fire on a chain grate stoker. This photograph was taken through an inspection door in the rear corner of the furnace. The coal was so fed to this stoker that fine coal existed at the quarter points and coarse coal was on each side and at the center. In the fine coal zones there has been less air flow through the coal than in the coarse coal zones. Note the heavy incompletely burned gases being given off by the fine coal. This condition would be even worse toward the front of the stoker.

A spreader stoker gives somewhat similar results. If fine coal exists in some of the feeders or in parts of the feeders, and the coarse coal is in the remainder, it will be found that the fine coal will not be thrown as far as the coarse coal; and, therefore, piling of the fine coal on the stoker grates will result, and a portion of the grate at the rear will be bare. Insufficient air will pass through the fine coal portions of the grate and an excess amount of air through the bare grate will cause production of smoke and the formation of clinkers on the grate where the fuel bed is heavy. This clinker further reduces the air and causes more smoke to be produced.

Underfeed stokers, particularly the multiple retort type, are likewise affected by coal segregation in a somewhat similar way.

To reduce smoke production, it is necessary to make the fire uniform. The elimination of coal segregation in the stoker hoppers will materially help attain that result. When the coal segregation on the chain grate of Figure 1 was eliminated, the fire became uniform across the width of the stoker and its appearance changed to that shown in Figure 2. Note the even depth of fuel across the stoker. Not only has smoke been eliminated, but, also, the efficiency of combustion and capacity has been increased and maintenance decreased.

Since smoke may be the result of bad fires, and bad fires the result of coal segregation, a study of coal segregation in boiler plants will indicate good designs for new plants and desirable changes in existing equipment.

Cause of Segregation

Just why does coal segregate? In order to answer that question, illustrations of coal segregation are presented herewith. This is done not with the idea of condemning one type of equipment or recommending another, but, rather, to point out how segregation occurs in each case, how to recognize the effects of such segregation, and what to do about it. When coal segregation in a boiler plant is considered, every step from the car to the inside of the furnace must be studied. Segregation caused early in this process sometimes cannot be subsequently corrected. Most of the causes of coal segregation in boiler plants are due to the equipment installed in the plant, or to the arrangement of that equipment. Operation of the plant is sometimes the cause of coal segregation, but the operators of the plant seldom have control over coal segregation, inasmuch as the segregation is usually within the equipment itself. However, there are certain pieces of equipment which can be operated satisfactorily or not, according to the attention given to them by the operators. In general, this type of equipment should be avoided.

In order to get an understanding of coal segregation, let us analyze the case of the typical flat chute such as has often been used to feed stoker hoppers. If a flat

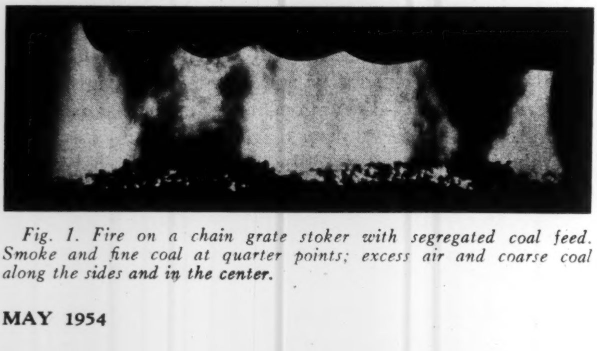

Fig. 1. Fire on a chain grate stoker with segregated coal feed. Smoke and fine coal at quarter points; excess air and coarse coal along the sides and in the center.

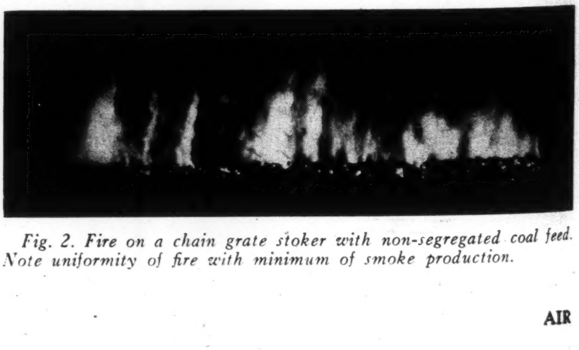

Fig. 2. Fire on a chain grate stoker with non-segregated coal feed. Note uniformity of fire with minimum of smoke production.

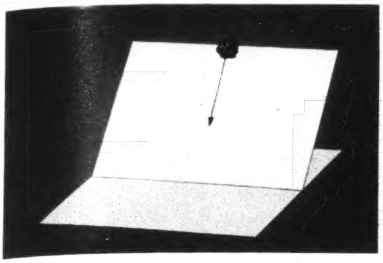

Fig. 3. Coal slides down steepest angle of an inclined plane.

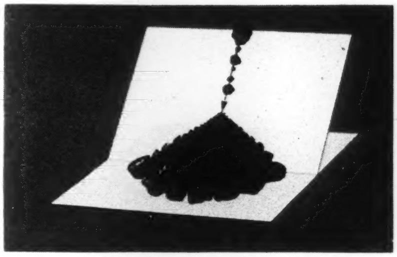

Fig. 4. Segregation in a pile.

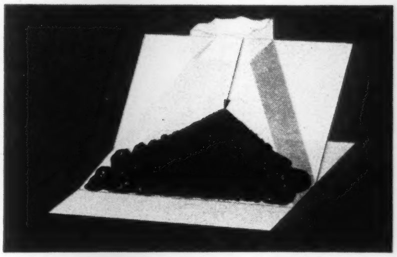

Fig. 5. Segregation in a typical flat chute.

plate were inclined to the horizontal, as shown in Figure 3, and a piece of coal were placed at its upper edge and then released, it would follow the steepest slope down the surface of the plate, as indicated.

A number of such pieces of coal released successively from the same starting point would form a pile at the bottom, as shown in Figure 4. The coarse coal would roll over this pile, away from the center of the plate, while the fine would sift through the coarse coal and remain at the center.

Two side guides could be added without changing the tendency for the coarse coal to roll and the fine coal to sift. The addition of a second plate placed parallel to the first, as shown in Figure 5, would form the usual straight fan-shaped chute.

If two flat chutes as described were used to feed a stoker hopper, there would be coarse coal on both sides and a coarse coal streak down the center. There would be fine coal zones down the quarter points. The center coarse coal streak as illustrated in Figure 6, and the type of fire which such an arrangement would produce is illustrated in **Figure 1.**

The amount of coal segregation in any installation depends upon the kind of coal, size consist, the moisture, the velocity, the direction of flow, and the size and shape of the passages through which the coal flows. A number of illustrations are presented herewith in order to indicate what happens under various conditions. It is not possible to indicate the quantitative amount of segregation that will result with the arrangements as shown. This accounts for the fact that a few installations of equipment which should give trouble are apparently working satisfactorily; whereas, under somewhat similar conditions with the same equipment, the results may be very bad.

Illustrations of Segregation

Figure 7 shows coal segregation as it would exist in the coal bunker fed by a flight conveyor without a trough. The conveyor fills the left end first. A pile is formed, the top of which moves toward the unfilled end. This method puts the coarse on the right-hand side of the illustration and the fine on the left-hand side.

In the case of the steel silo with a vertical center feed, Figure 8, it will be found that fine coal collects in the

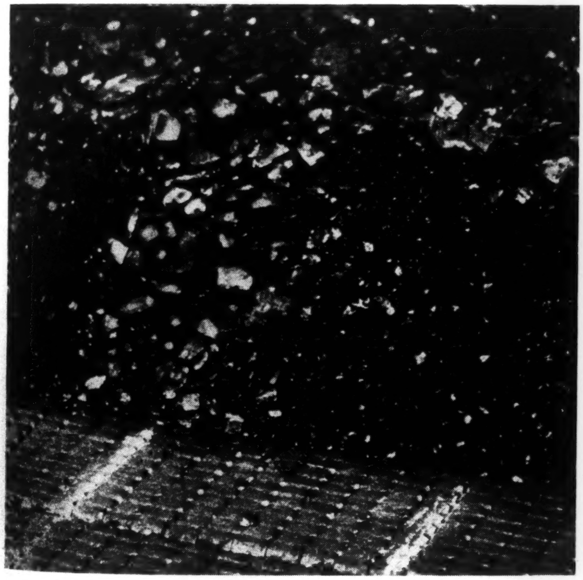

Fig. 6. A coarse coal streak down center of chain grate caused by junction of two flat chutes.

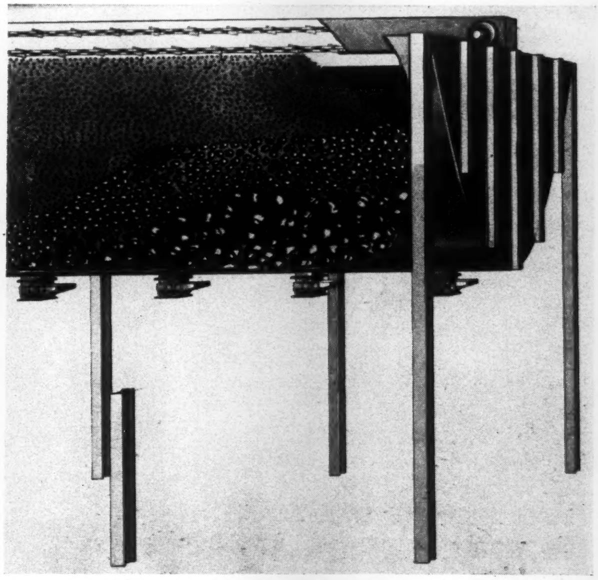

Fig. 7. Segregation in coal bunker fed by flight conveyor without trough.

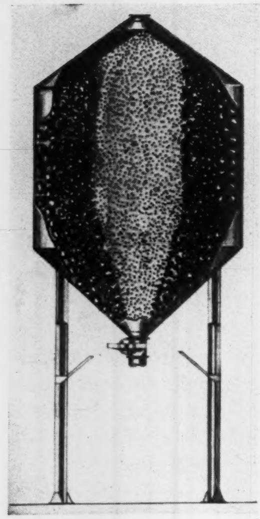

Fig. 8. Coal segregation in silo with vertical center feed.

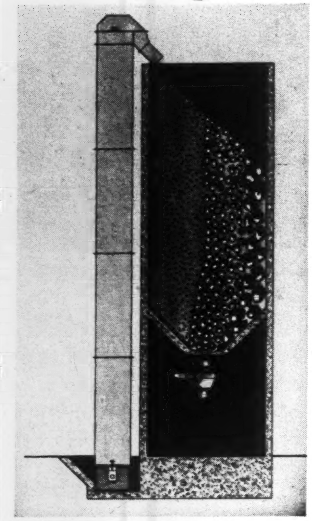

Fig. 9. Coal segregation in silo fed from side.

center of the silo and the coarse will distribute itself around the periphery. When coal is withdrawn from such a silo, fine coal comes out first followed by a mixture which progressively becomes coarser.

In the case of a concrete silo, as shown in Figure 9, it will be found that a fine-coal core exists on the side near the elevator and the coarse material exists on the side away from the elevator. As coal is withdrawn from such a silo, it will be found that the coarse coal remains on the right-hand side of the outlet downspout or chute and fine coal on the left-hand side. If coal from such a bunker is fed to a stoker hopper whose long dimension is parallel to the plane of the illustration, it would be found that the coarse material would practically all exist on the right side of the stoker hopper, and the fine coal on the left side. Such an installation would result in a very poor fire.

If the long dimension of the stoker hopper were perpendicular to the plane of the illustration and were on the right side, then the coarse material would find itself next to the boiler, and the fine material on the side away from the boiler. Fuel so segregated causes little or no difficulty in burning.

When coal slides down a sloping downspout, the coarse coal gradually rises to the top of the downspout and the fine coal sinks to the bottom. Figure 10 illustrates this condition. Trouble exists in many installations of two single-retort stokers that are fed from one side because of this fact. Figure 11 shows such an installation. Inasmuch as the fine coal settles to the bottom of the downspout, the right-hand stoker hopper receives the coarse coal, whereas, the left-hand stoker hopper receives the fine coal.

Figure 12 shows segregation as it takes place within the typical apron-feed hopper scale. The coal slides off the head pulley of the feeder in such a manner that it throws the greatest amount of coarse coal to the right-hand side of the weigh hopper. In the event the coal scale is installed with the feed belt parallel to the stoker hopper, then the coarse coal will be at one end of the stoker hopper and fine coal at the other. But if the coal scale is installed with its feed belt running toward the boiler front, then the coarse coal will be on the boiler side and the fine coal will be on the aisle side and no trouble will be experienced.

Figure 13 shows a flat chute feeding a stoker hopper which has its inlet flange on the left side. This design puts a large proportion of the coarse coal on the right-hand side and the fine coal on the left-hand side. Such an eccentric flat chute causes a greater amount of segregation than the center-feed flat chute.

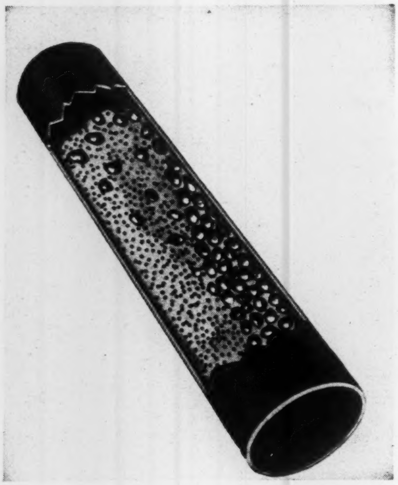

Fig. 10. Segregation in an inclined downspout.

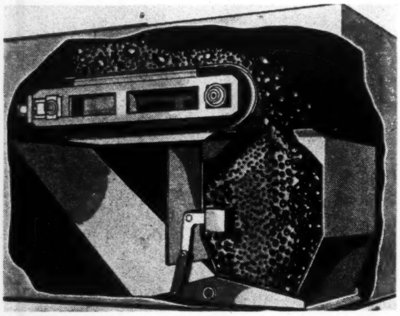

Fig. 12. Segregation in weigh hopper of coal scale.

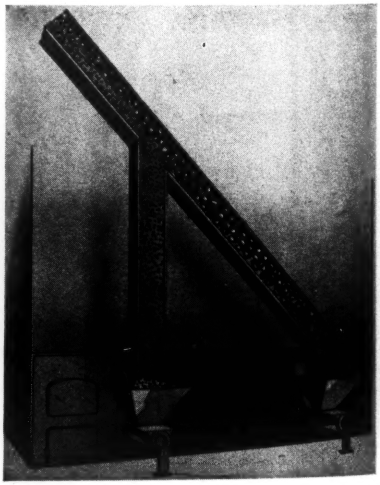

Fig. 11. Two stokers fed with single lateral downspout.

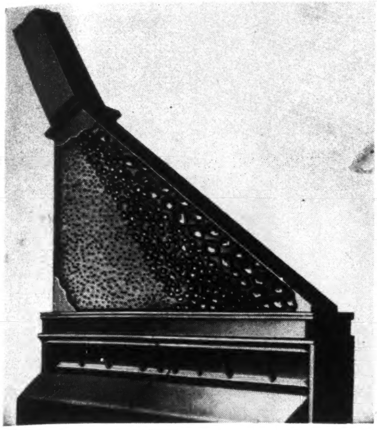

Fig. 13. Segregation in flat chute fed from left-hand side.

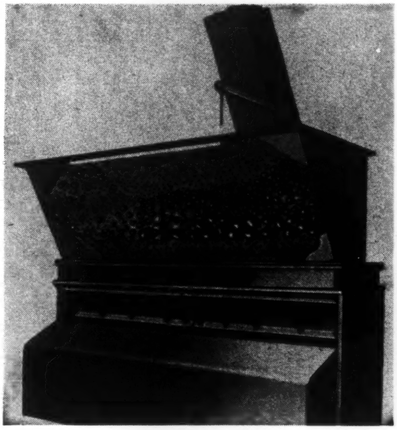

Fig. 14. Segregation in stoker hopper extension caused by infrequently operated weigh larry. (Larry moved from left to right.)

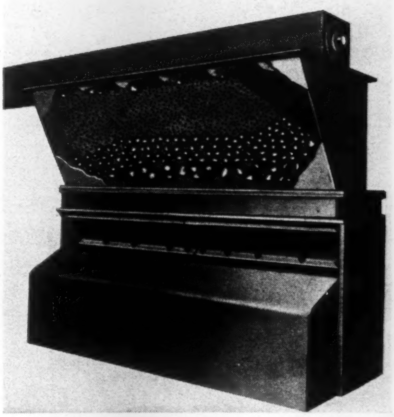

Fig. 15. Segregation in stoker-hopper extension caused by intermittently operated screw conveyor.

Figure 14 illustrates the type of coal segregation that results from an infrequently operated weigh larry. This type of operation causes a coarse-coal seam that runs across the flow of the coal. A similar coal segregation pattern is caused by a screw conveyor which is installed along the top of the stoker hopper and is operated only periodically. This is illustrated in Figure 15.

Appearance of Fires With Segregated Fuel

The effect of the segregation caused by the simple fan type of chute on the fire is illustrated in Figure 16. Note the short fire along the sides of the stoker and also the erosion of the side walls and arch where the combustion rate is high. The short fire uncovers part of the stoker, allowing excess air to pass through and the stoker iron to be damaged. Also, note the long fire in the center where unburned fuel is dumped into the ash pit. Smoke is produced down the center of such a fire. Similar fires are the result of a single downspout, a weigh larry, or swinging spout which is allowed to stand with free discharge in the center of the stoker hopper.

Figure 17 shows the type of fire that results when the coarse coal is all on the one side and the fine coal on the other, such as would be the case if the arrangement of equipment as shown in Figure 13 were employed. Smoke from such a fire will be produced along the right-hand side.

With the type and operation of equipment shown in Figure 14 and 15, segregation will result in the fire, as shown in Figure 18. These cross-holes in the fire will have the same time frequency as the frequency of operation of the stoker hopper filling the equipment. Many operators do not recognize this type of segregation since it is periodic and not of the streak type. In many cases, it can be eliminated or reduced by more frequent filling of the stoker hopper.

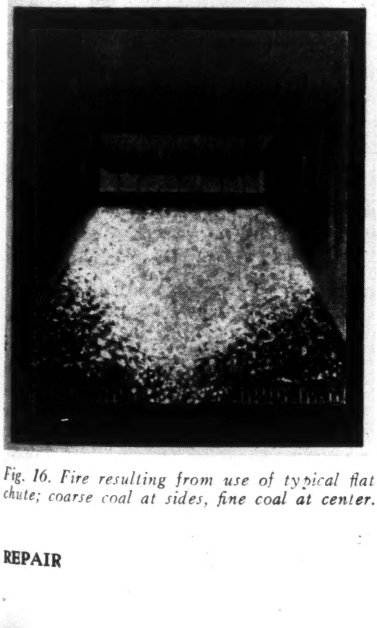

Fig. 16. Fire resulting from use of typical flat chute; coarse coal at sides, fine coal at center.

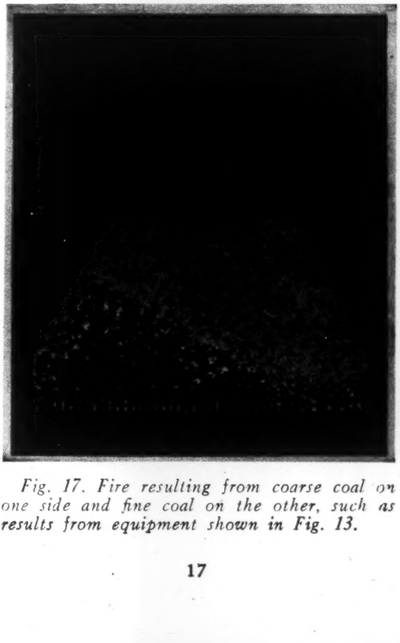

Fig. 17. Fire resulting from coarse coal on one side and fine coal on the other, such as results from equipment shown in Fig. 13.

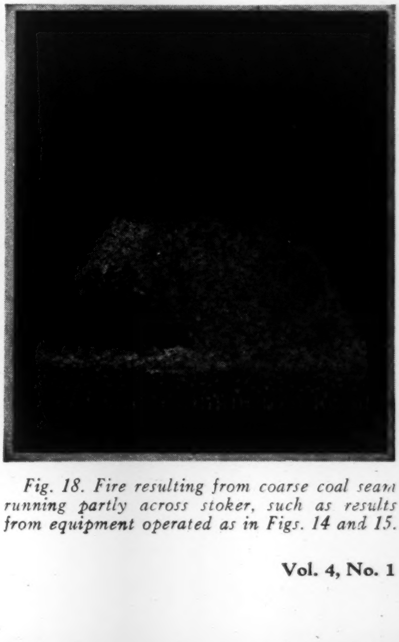

Fig. 18. Fire resulting from coarse coal seam running partly across stoker, such as results from equipment operated as in Figs. 14 and 15.

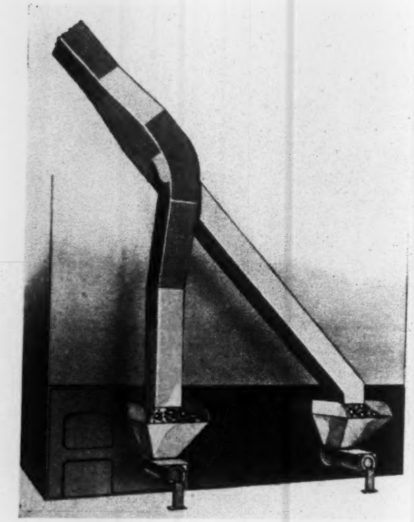

Fig. 19. Downspout division arrangement to offset lateral downspout segregation.

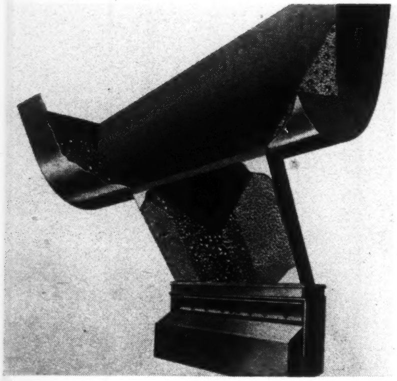

Fig. 21. Segregation in constant-width chute with low bunker.

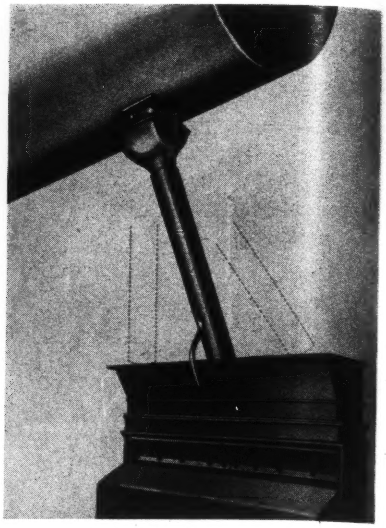

Fig. 20. Hand-swung spout.

Elimination of Coal Segregation

What should be done in order to correct coal segregation? Bunker segregation in general can be eliminated to a certain degree by multiple points of loading. In the case of a flight conveyor, as shown in Figure 7, a trough should be provided with outlet gates. These gates should be opened and closed in such a manner that the bunker will be loaded in horizontal layers instead of from one end. In the case of a silo with center feed, as shown in Figure 8, or a concrete silo, as shown in Figure 9, it is often possible to reduce the amount of bunker segregation by the employment of chutes within the silo or bunker. The chutes should be so designed that they will carry coal to several points in the bunker and thereby reduce the amount of bunker segregation by division. These chutes are built with open tops so that, when the bunker is nearly full, the chutes are flooded. Hence, the bunker capacity is not reduced.

Also, in some cases of silo segregation, it is possible to move the elevator 90° in plan and thereby change the segregation pattern to one that will do little harm to the fire. Segregation in downspouts can be eliminated by turning the discharge of the downspout toward or away from the boiler.

In order to eliminate coal segregation in downspouts feeding two or more stokers, as shown in Figure 11, a vertical division of the coal flow should be made, as shown in Figure 19. The elimination of segregation caused by coal scales can be accomplished by so arranging the scale that the feed belt flows toward or away from the boiler.

There are numerous means of eliminating segregation caused by chutes or distributors which put the coal into the stoker hopper. Some plants reduce the air flow under those portions of the stoker that receive the coarse coal. In other words, air segregation is caused to offset coal segregation. Such a procedure is far from satisfactory because changes in the size and type of coal require a change in air dampers. Even with a mixture that remains the same from hour to hour, it is impossible to adjust the air dampers exactly. This method also reduces the maximum steaming capacity of the stoker.

Many plants have employed the hand-swung spout, as illustrated in Figure 20. This arrangement consists of a single pipe-like spout with a hinged upper portion. A handle is provided so that the operators can swing the downspout from side to side. The angle of the swing should be maintained at the minimum. Otherwise considerable force is required to swing the spout over the full width of the stoker hopper. For this reason, the employment of hand-swung spouts is usually limited to small installations. The length of the spout should be as great as possible to keep the angle of swing small. For best results, the spout should be swung frequently, it should be swung the full width of the stoker hopper, and a coal valve at the spout outlet should be closed after the spout has been swung. It is possible to install a plate across the center of the stoker hopper to stop the flow of coal when the spout is in the vertical position. Such a plate is the equivalent of an automatic coal valve. Its employment will assist the operator in getting better results.

Mechanically operated swinging spouts are available in some European countries. These give satisfactory results from the segregation point of view if the spout is reasonably rapid. In order to make a good installation, considerable head room is required, and, of course, maintenance problems exist with the swinging mechanism.

Baffles have been installed within the flat fan-shaped chutes in an attempt to eliminate the segregation caused within these chutes. Designs of baffles have taken numerous forms. In some cases they help a little; usually

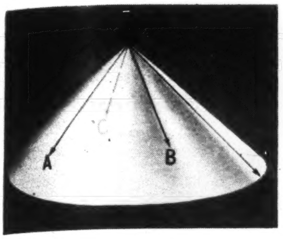

Fig. 22. Coal slides down any element of a cone.

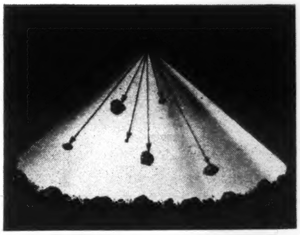

Fig. 23. Coal distributed around cone regardless of size of coal.

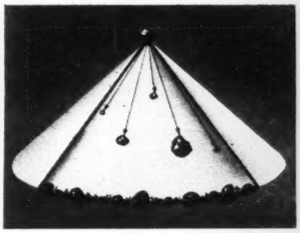

Fig. 24. Sector of a cone works same as a complete cone.

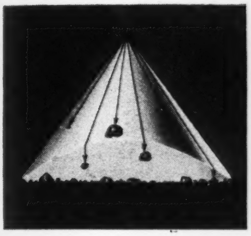

Fig. 25. Lower edge of cone removed in order to make conical distributor.

they impede the flow of coal to such an extent that they prove to be unsatisfactory. In no case, however, can baffles installed in a flat chute be considered as giving more than partial results. Therefore, they are not to be considered as non-segregating chutes.

In some plants a chute the full width of the stoker hopper is run up to the bunker. Since there is no change in cross-sectional area, such a chute will not cause segregation within itself. However, this design makes it imperative that there be no bunker segregation, otherwise the bunker segregation will travel directly through the chute itself. Likewise, the length of the bunker should be substantially the same dimension as the length of the stoker hopper. If the bunker is longer than the width of the chute, then serious segregation will exist when the bunker is low because the coal fills the chute from the parts of the bunker not directly in front of this stoker. Such a condition is illustrated in Figure 21.

A somewhat similar design has been developed in recent years for use with spreader stokers. In this case, an individual spout is run to each section of the spreader stoker. There should be substantially the same amount of coal immediately above the bunker outlet that feeds each spout. If this is not the case, then the center bunker outlets will empty first and cause side rolling in the bunker. This means that the last coal used by the center outlet will be almost nothing but coarse coal. There is a tendency for boiler house designers to consider all of the coal in the bunker above such an arrangement as being available to the stoker; whereas, if the center outlet runs out of coal first, the remaining coal in the bunker does not have any value to the operator.

Weigh larries can be employed to eliminate segregation in stoker hoppers. In order to do so, it is necessary to move them frequently from one side of the stoker hopper to the other. It is also necessary to close the coal valve at the weigh-larry hopper outlet so that the larry does not discharge freely into the stoker hopper when it is standing still. If the larry is moved sideways at infrequent intervals, segregation will be caused, as shown in Figure 14, and if the larry is allowed to stand with free discharge of coal, the segregation will be caused in the stoker hopper, as shown in Figure 5.

Good results or poor results will be obtained with the larry, depending upon whether or not the operators put sufficient effort into their job to get a reasonably non-segregated fuel feed to their stokers.

The conical design of distributor has proved to be satisfactory in eliminating chute segregation. The operation of this type of chute or distributor may be explained as follows: If a lump of coal were placed at the apex of a cone, the axis of which is vertical, and then released, it would slide down any element of the cone, such as A, B, C, or D, Figure 22. Now, if a number of pieces of coal were placed at the apex of the same cone and released, the condition shown in Figure 23 would result wherein all of the coal, regardless of its size or shape, would be equally distributed around the cone.

A segment of the cone, as in Figure 24, would produce the same result. In order to deposit the coal along a straight line, the conical segment is cut by a vertical plate, as in Figure 25. The coarse and fine coal remain uniformly mixed in this vertical drop, since the flow of the coal particles is parallel. The conical non-segregating coal distributor is formed by adding to such a conical segment two side plates, an entrance flange, and another similar conical segment to act as a cover plate. Figure 26 shows the typical installation of such a distributor on a spreader stoker.

Air and Moisture Segregation

In addition to coal segregation, there are two other forms of segregation which affect firing results on stokers,

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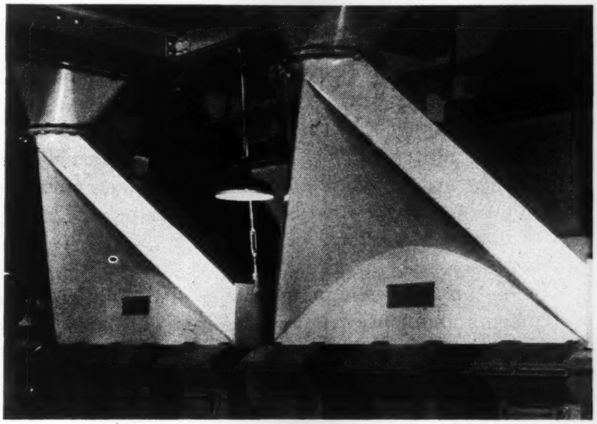

Fig. 26. Typical installation of conical distributor.

Increased Efficiency And Decreased Smoke With Boiler Instruments And Controls

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It is indeed fortunate that the laws of nature decree that in nearly any combustion process, a decrease in the smoke production will increase the combustion efficiency and vice versa. Consequently, the elimination of smoke from a combustion process does not become solely a matter of public relations and good neighborliness, but also one of increased efficiency.

Boiler furnaces constitute one of the largest users of fuel in the United States, and this paper will deal primarily with boiler furnaces for the generation of steam for power and process purposes, in what is generally considered the small and medium size class. Very small boilers, say under 100 h.p. are not considered here, nor are the very large central station type of boilers, although the principles involved are the same in either case.

The very small boilers do not burn sufficient fuel to warrant much of an expenditure for instruments and controls, despite rather high percentage savings which may be effected; and the very large central station type of boilers are normally equipped with a complete complement of instruments and controls, since the total cost of fuel is so high that utilizing the fuel to the utmost is an absolute necessity.

There are many boilers in operation today having maximum steaming rates between 10,000#/hr and 300,000#/hr which are not being operated with realistic efficiency judged by present day standards, and it is axiomatic that many of these plants are included in the list of serious offenders from the standpoint of air pollution. Since the two problems are inherently common, the solution of one in most instances solves the other.

The original selection of major equipment and auxiliaries for any plant has considerable bearing on the maximum efficiency which can be obtained, and the minimizing of a smoke nuisance. Once the equipment has been selected and installed, however, the problem then becomes a matter of operation, or of expensive replacement of capital equipment. It is along the lines of improved operation that instruments and controls lend a helping hand, and in many cases offer a near complete solution to the problem.

The objectives in equipping a boiler plant with suitable instruments and controls may be stated as follows:

1. Increased efficiency
2. Reduced smoke
3. Ability to handle variable loads
4. Safety and reliability

Increased efficiency in a boiler plant is obtained by maintaining the steam pressure at its proper value, in order to keep turbine efficiency at its top point, maintaining the proper steam temperature for peak turbine performance, and properly proportioning fuel and air for maximum combustion efficiency. In many plants, control of steam temperature is not provided in the major equipment design, and the steam temperature is inherent in that design. In these cases, no direct control of temperature is possible.

By properly proportioning and distributing fuel and air at all times, the emission of smoke from the stack is held at a minimum, even under variable load conditions.

The instruments and controls should be such that the variable loads which may be placed on the plant may be handled readily without decrease in efficiency, without even temporary production of excessive smoke, and without extra attention from the boiler operators.

A properly applied instrument and control system will accomplish these things with increased safety and reliability for the entire plant.

Instruments

There are many instruments available for power plant use, such as pressure gages, temperature indicators, flow meters, level measuring devices and the like. These conventional instruments are well understood by engineers and designers of steam generating plants, and are generally available from several sources.

For many years, the Bailey Boiler Meter has been considered the standard combustion guide for boiler furnaces. This instrument records steam flow and air flow through the furnace on a common chart, and is so adjusted that the records coincide when peak combustion conditions are obtained. The steam flow is an index of heat released from the furnace, and the air flow an index of heat supplied to the furnace, so that the use of the relationship is fundamentally correct under all steady state conditions. There are times, however, when under rapidly changing conditions, the thermal inertia of the boiler setting and other auxiliaries will permit a transient error in the Boiler Meter, which may cause temporary periods of inefficient combustion and smoking. For steady state conditions, the Boiler Meter is unquestionably the most reliable and accurate operating guide available, but for many applications, especially where variable loads occur, it needs to be supplemented by some of the newer developments in boiler instruments.

Once the basic plant and its auxiliaries have been designed and installed, combustion efficiency is determined primarily by the amount of Excess Air which is supplied for combustion. Figure 1 illustrates the relationship between flue gas analysis and Excess Air for various types of commercial fuels, and it will be noted that for a given Excess Air, the spread in the analysis of CO^2 is very great. Even for a single fuel, the deviation from the lines illustrated is of considerable magnitude. It will be noted, however, that the Oxygen curves are largely coincidental over the normal range of operation, so that the measurement of oxygen in the flue gases gives a direct and accurate measurement of the Excess Air. If a gas sample is withdrawn from the furnace, properly conditioned and analyzed in a very short period of time, it becomes an excellent indication of combustion conditions under rapidly changing loads and steady loads.

Such a device is illustrated by Figure 2. A washing and cooling system withdraws a sample from the furnace, thoroughly conditions it for analysis and delivers it through the filter to the gas analyzer in about five seconds. The analyzer itself responds instantly, and registers about 60% of the change within 10 to 15 seconds. Thus, the recorder shows the actual Excess Air in the furnace within a very few seconds.

This analyzer employs the catalytic combustion principle, where the gas sample and hydrogen introduced as a fuel are passed over a catalyst filament, initially heated electrically, so that combustion of the excess Oxygen in the gas sample in the presence of the hydrogen fuel further increases the temperature of the filament by an amount proportionate to the Oxygen content. Inasmuch as the catalyst filament is in itself resistance responsive to temperature changes, a simple bridge circuit is properly calibrated to record percent Oxygen or Excess Air directly.

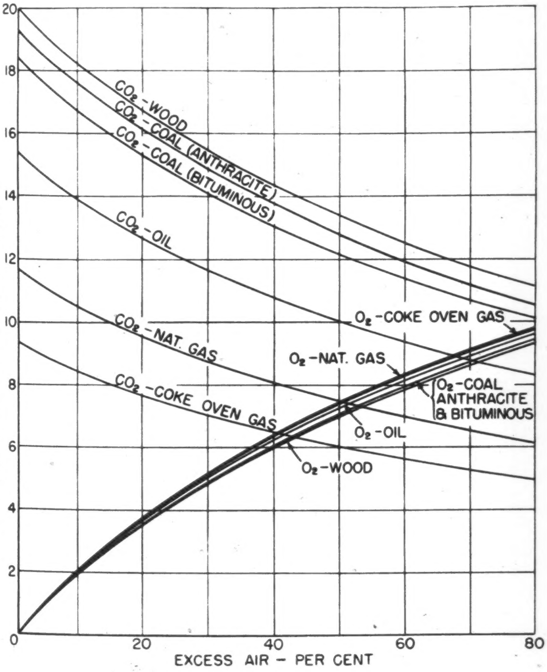

Fig. 1. Relationship between excess air and flue gas analysis.

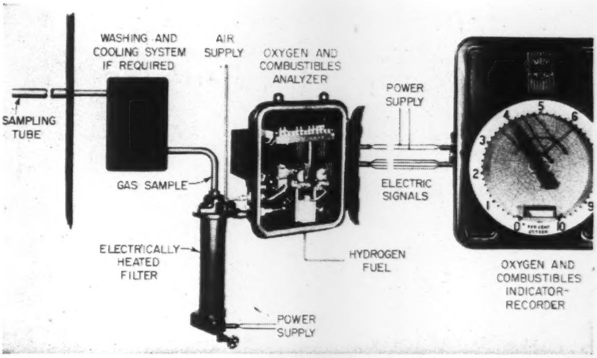
WASHING AND COOLING SYSTEM IF REQUIRED
AIR SUPPLY
OXYGEN AND COMBUSTIBLES ANALYZER
POWER SUPPLY
SAMPLING TUBE
GAS SAMPLE
ELECTRIC SIGNALS
ELECTRICALLY HEATED FILTER
HYDROGEN FUEL
OXYGEN AND COMBUSTIBLES INDICATOR-RECORDER
POWER SUPPLY

Fig. 2. Combination oxygen and combustibles analyzer.

Considerable use has been made of this instrument both for normal operating conditions as a guide for the operator and as an index for automatic control, and it has also been used to considerable advantage with a portable sampling tube for studying stratification within the furnace, the proper adjustment of distribution dampers, and the study of erratic conditions produced by some other auxiliary equipment. Equipped with a high speed chart, cycling variations on the order of one second may be readily detected, and once detected, the solution can usually be found and corrective action taken.

In any combustion process, reduction of Excess Air below a certain minimum will produce unburned combustibles in the flue gases, and these unburned combustibles can and do decrease the efficiency of the process, as well as increase the possibility of excess smoke. Combined in the Oxygen analyzer illustrated is a second filament, over which a mixture of the sample and a small amount of compressed air is passed, and any unburned combustibles present in the sample will increase the temperature of this filament so that the percentage of unburned gases may be recorded. A second pen shown on the recorder will continuously record the amount of combustible gases present, and can be equipped to sound alarms if they become excessive.

Inasmuch as the unburned combustibles actually consist of many components, the analyzer is normally furnished with a calibration arbitrarily based on hydrogen, and the comparative readings for the other constituents normally found in commercial combustion furnaces is illustrated by Figure 3.

The realization of the cause of many explosions in gas fired furnaces led to the consideration and approval of this device by Factory Mutual Insurance Association as a combustion safeguard. For this service, the instrument is equipped with two contacts, one of them set at 1.5% combustibles for an alarm, and a second which may later be connected up as a trip for the furnace, set at about 3%.

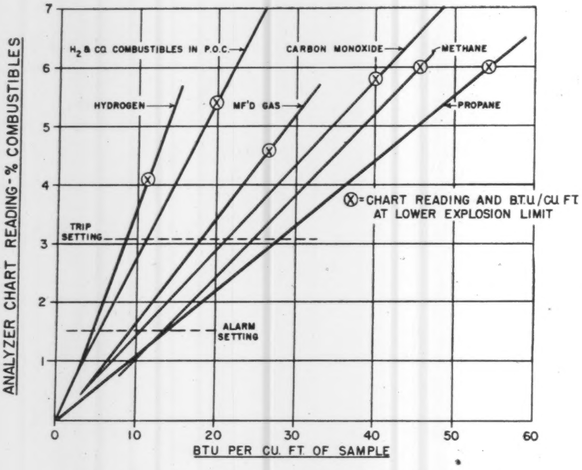

Fig. 3. Btu and lower explosive limit of combustible gases.

Figure 4 illustrates the installation of another instrument as a check on combustion conditions—a Smoke Density Recorder. The design of this instrument is a result of many years experience in the manufacture of smoke density instruments and incorporates features found desirable from the experience.

A light source, consisting of a sealed beam projection spot lamp, is focused across the duct where the smoke is to be measured, onto a glass sealed Bolometer. The Bolometer is a temperature sensitive filament placed at the focal point of a parabolic mirror in such a way that the temperature of the filament, and consequently its resistance, is a function of the energy transmitted across the smoke passage by the light source. While most photoelectric devices are quite fragile, of short life and badly affected by high ambient temperatures, the sealed Bolometer is mechanically rugged, has a very long life, and is not adversely affected by high ambient temperatures. An ambient temperature compensator is installed adjacent to the Bolometer so that variable ambient temperatures do not affect the reading.

A simple AC electronic recorder is connected to the Bolometer and calibrated so that a zero reading is obtained with no smoke in the passage and 100% reading obtained when no light is transmitted. A linear calibration between these two points corresponds approximately to the Ringlemann scale, with 20% corresponding to Ringlemann No. 1, 40% No. 2, 60% No. 3 and so on.

In smoke measurement installations, the alignment of the light source and the receiver unit has been a continual source of difficulty, and is alleviated in this installation by installing both units on opposite ends of the same piece of pipe which is installed across the smoke passage. Slots are installed in the pipe parallel to the path of smoke travel.

It is well known that a column of smoke in a narrow column will appear considerably less dense than the same smoke in a thick column. Because of this, a standard 5 foot width of slot is installed in the pipe so that the readings are not affected by the total width of the smoke passage.

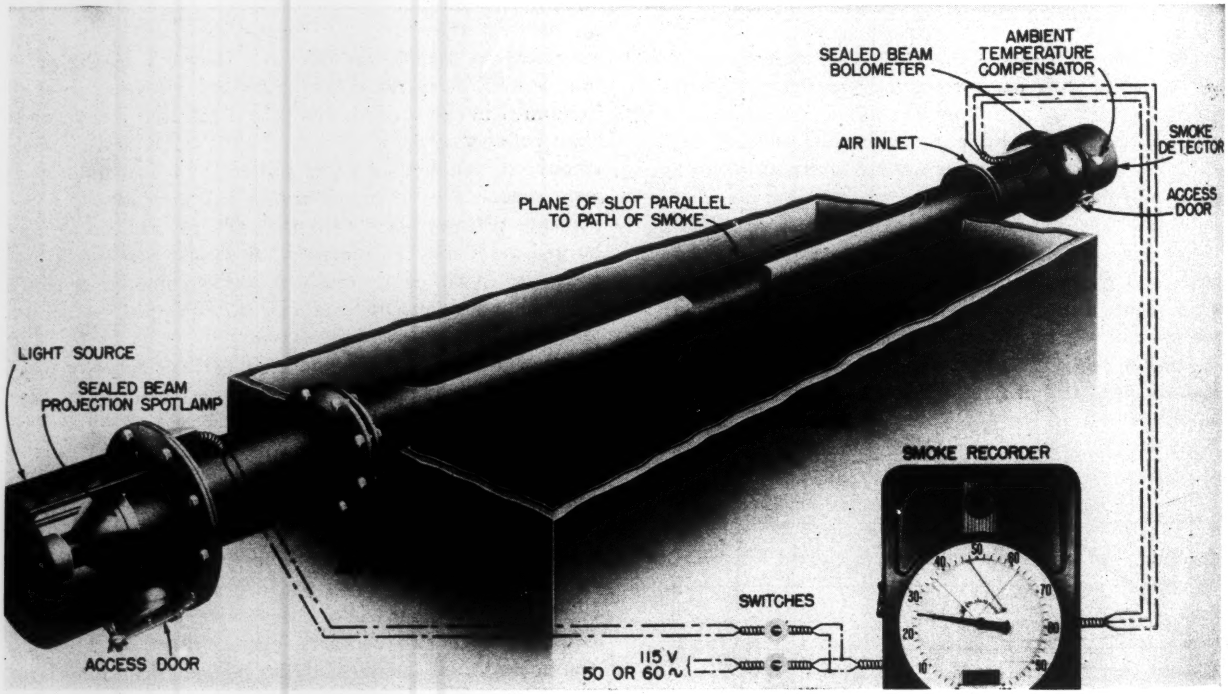

Fig. 4. Smoke density measuring system.

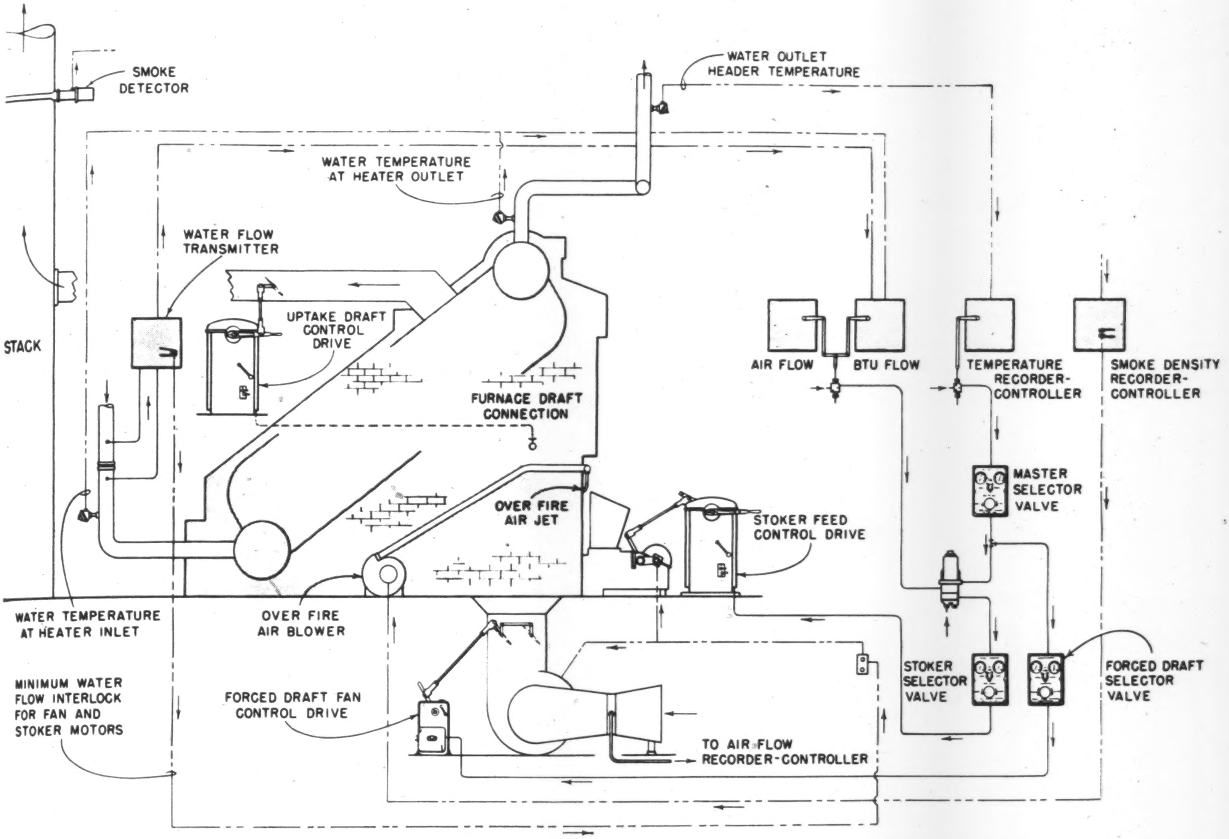
SMOKE DETECTOR
WATER OUTLET HEADER TEMPERATURE
WATER TEMPERATURE AT HEATER OUTLET
WATER FLOW TRANSMITTER
UPTAKE DRAFT CONTROL DRIVE
STACK
AIR FLOW
BTU FLOW
TEMPERATURE RECORDER-CONTROLLER
SMOKE DENSITY RECORDER-CONTROLLER
FURNACE DRAFT CONNECTION
MASTER SELECTOR VALVE
OVER FIRE AIR JET
STOKER FEED CONTROL DRIVE
WATER TEMPERATURE AT HEATER INLET
OVER FIRE AIR BLOWER
MINIMUM WATER FLOW INTERLOCK FOR FAN AND STOKER MOTORS
FORCED DRAFT FAN CONTROL DRIVE
STOKER SELECTOR VALVE
FORCED DRAFT SELECTOR VALVE
TO AIR FLOW RECORDER-CONTROLLER

Fig. 5. Combustion control system for small coal-fired water heating boiler.

These two instruments, used in conjunction with the more conventional type of boiler furnace instruments which have been in use for many years, assist the operator in keeping a continual check on actual operating conditions, and assist in increasing efficiency and reducing the possibility of smoke.

Combustion Controls

Automatic combustion control, utilizing the measurements discussed above, permits the operation of furnaces with a minimum of operator attention and with a continual check on actual combustion conditions. While only a few years ago this class of equipment was confined mostly to the larger plants, its use in small and medium size plants has grown considerably, and the time is readily forseeable when all furnaces of an industrial nature will be equipped with automatic control equipment.

Figure 5 illustrates the installation of automatic control equipment on a small coal fired water heating boiler used for heating the main plant of the Bailey Meter Company. Unlike the steam boiler, the measurement of heat output cannot be handled by a device as simple as a steam flow meter. It is necessary to make a measurement of Btu absorption of this unit, and this is accomplished by measuring the water flow through the boiler, the inlet and outlet water temperatures, and multiplying the flow by the temperature difference. Other than this, the instruments employed are conventional boiler plant type of equipment.

The master control in this case comes from a measurement of water outlet header temperature which acts through the master selector valve to adjust the stoker speed and the position of the forced draft dampers. A self contained furnace draft controller adjusts the position of the uptake damper.

While the stoker speed and forced draft are adjusted in parallel from the outlet temperature, a readjustment of the stoker speed is made from the relation of Btu flow and air flow to the furnace. This corresponds to the Boiler Meter, utilizing steam flow and air flow measurements, as normally used in the steam boiler. The readjustment provides a continual check on actual combustion operation, and provides for automatic maintenance of a high degree of efficiency, and a minimum of smoke.

As a further check, a smoke density recorder is installed in the stack so that manual adjustments can be made to the stoker setting or adjustment made to the overfire jets if at times the amount of smoking does exceed the permissible amount.

A small steam boiler fired by a spreader stoker and equipped with a forced draft fan is illustrated by Figure 6. A measurement of steam outlet pressure provides the master control signal, which operates through hand-automatic selector valves and adjusts the stoker speed and the forced draft damper position in parallel. The Boiler Meter, utilizing steam flow and air flow measurements, provides a continuous readjustment of the forced draft damper in order to provide optimum combustion conditions with minimum smoke. A self contained furnace draft controller continually adjusts the position of the uptake damper. Smoke recorders and oxygen recorders are frequently installed as further checks on boilers of this general type, especially in the middle sizes and smoke recorders in particular are being utilized more and more on boilers of all sizes.

Figure 7 illustrates the application of automatic control equipment to a moderate sized utility or large industrial type of boiler, utilizing pulverized coal as a fuel. This boiler is designed to operate at high pressures and high controlled temperatures, and is equipped with heat recovery equipment in the form of economizers and air preheaters.

Steam outlet pressure provides the master control signal which through suitable relay equipment automatically adjusts the fuel feed, forced draft, and induced draft in parallel. Furnace draft measurement is utilized to readjust the position of the induced draft damper to maintain a constant draft within the furnace, and the forced draft dampers are readjusted by a measurement from the Boiler Meter.

A constant suction within the pulverizer is automatically controlled by positioning a damper in the hot air duct to the pulverizer, and remote manual control is provided for the tempering air damper.

Feed Water Control for this boiler consists of a control valve in the feed water line, which is positioned by measurement of steam flow from the boiler, feed water flow to the boiler and level within the boiler drum. This three element system of feed water control will handle all steady state and variable load conditions which may be imposed on the boiler.

Automatic steam temperature control is provided in this boiler by by-passing some of the steam from the primary superheater through a submerged de-superheater in the mud drum before it goes to the secondary superheater. The amount of steam is adjusted by a control valve installed in a steam line in parallel with an adjustable orifice, and is automatically positioned by a measurement of air flow, which is indicative of load on the boiler, and

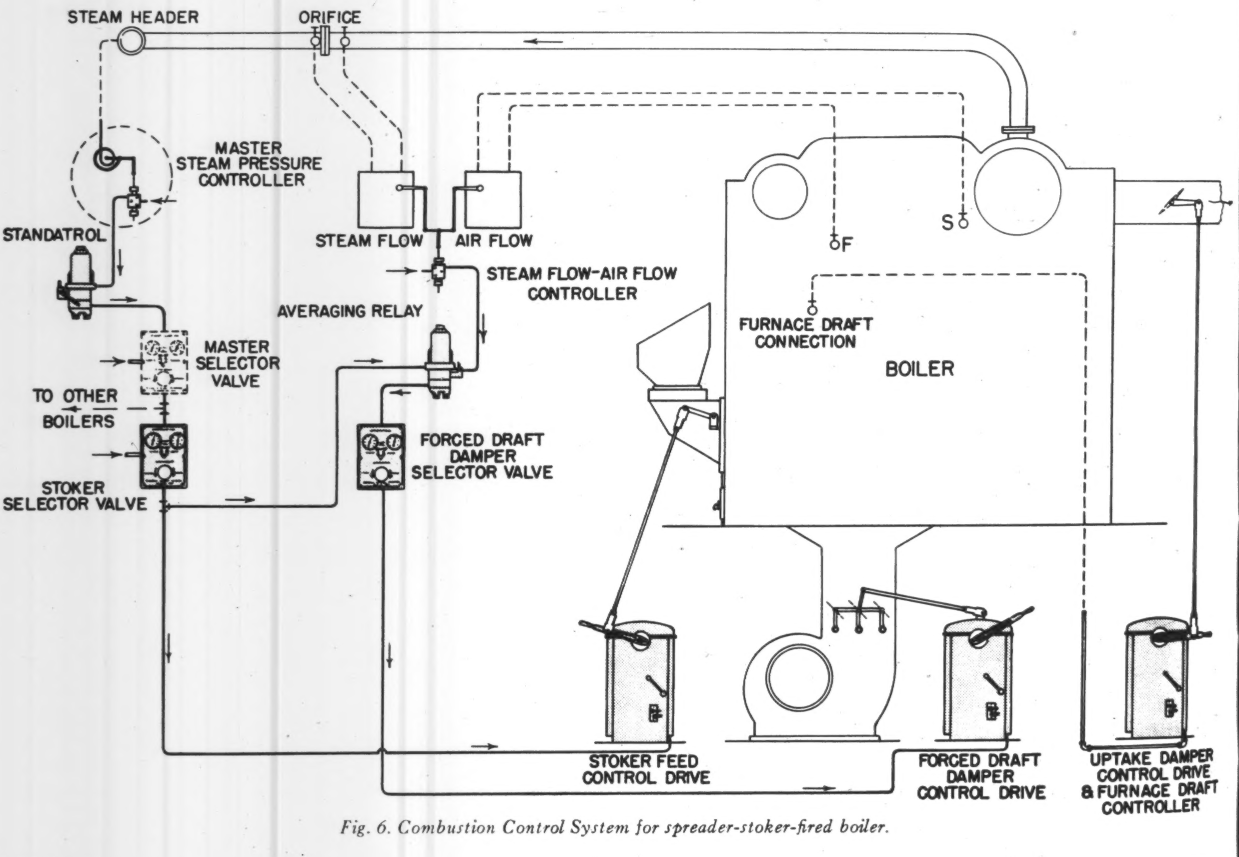
STEAM HEADER
ORIFICE
MASTER STEAM PRESSURE CONTROLLER
STANDATROL
STEAM FLOW
AIR FLOW
STEAM FLOW-AIR FLOW CONTROLLER
AVERAGING RELAY
MASTER SELECTOR VALVE
TO OTHER BOILERS
STOKER SELECTOR VALVE
FORCED DRAFT DAMPER SELECTOR VALVE
F
S
FURNACE DRAFT CONNECTION
BOILER
STOKER FEED CONTROL DRIVE
FORCED DRAFT DAMPER CONTROL DRIVE
UPTAKE DAMPER CONTROL DRIVE & FURNACE DRAFT CONTROLLER

Fig. 6. Combustion Control System for spreader-stoker-fired boiler.

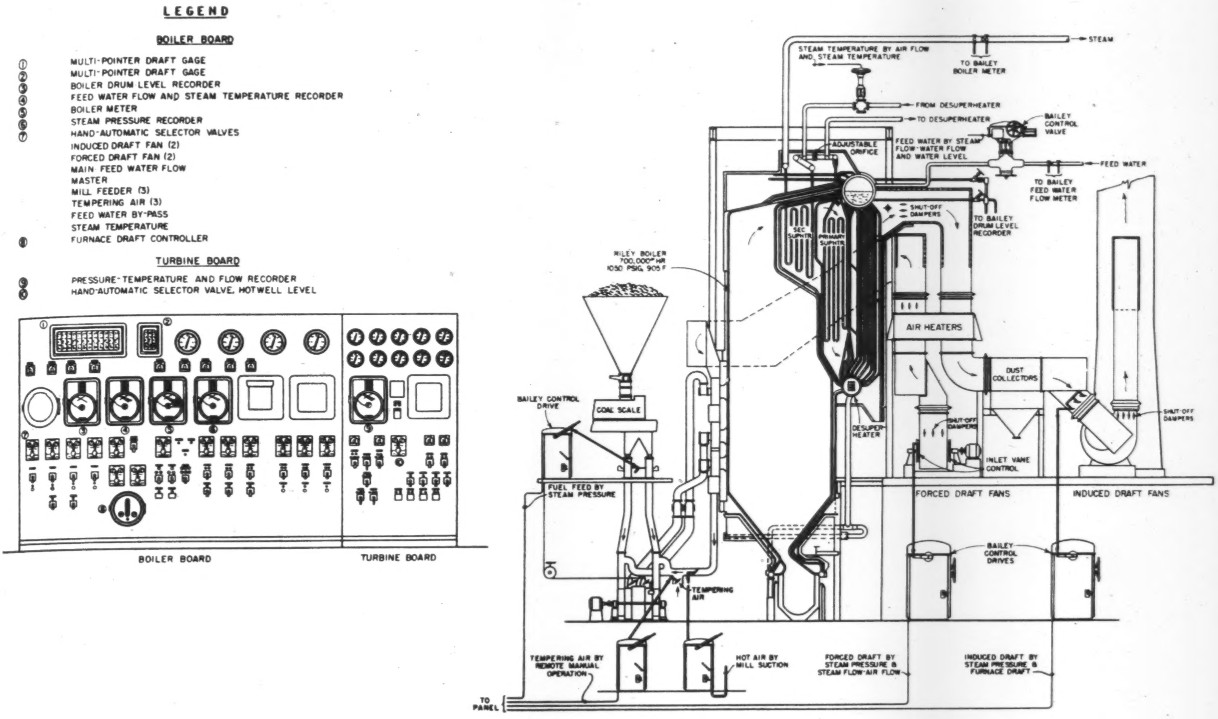
LEGEND
BOILER BOARD
① MULTI-POINTER DRAFT GAGE
② MULTI-POINTER DRAFT GAGE
③ BOILER DRUM LEVEL RECORDER
④ FEED WATER FLOW AND STEAM TEMPERATURE RECORDER
⑤ BOILER METER
⑥ STEAM PRESSURE RECORDER
⑦ HAND-AUTOMATIC SELECTOR VALVES
INDUCED DRAFT FAN (2)
FORCED DRAFT FAN (2)
MAIN FEED WATER FLOW
MASTER
MILL FEEDER (3)
TEMPERING AIR (3)
FEED WATER BY-PASS
STEAM TEMPERATURE
⑧ FURNACE DRAFT CONTROLLER
TURBINE BOARD
⑨ PRESSURE-TEMPERATURE AND FLOW RECORDER
⑩ HAND-AUTOMATIC SELECTOR VALVE, HOTWELL LEVEL
BOILER BOARD
TURBINE BOARD
STEAM
STEAM TEMPERATURE BY AIR FLOW AND STEAM TEMPERATURE
TO BAILEY BOILER METER
FROM DESUPERHEATER
TO DESUPERHEATER
BAILEY CONTROL VALVE
ADJUSTABLE ORIFICE
FEED WATER BY STEAM FLOW-WATER FLOW AND WATER LEVEL
FEED WATER
TO BAILEY FEED WATER FLOW METER
SHUT-OFF DAMPERS
TO BAILEY DRUM LEVEL RECORDER
SEC SUPHTR
PRIMARY SUPHTR
RILEY BOILER 700,000# HR 1050 PSIG, 905 F
AIR HEATERS
DUST COLLECTORS
SHUT-OFF DAMPERS
SHUT-OFF DAMPERS
DESUPER-HEATER
INLET VANE CONTROL
BAILEY CONTROL DRIVE
COAL SCALE
FUEL FEED BY STEAM PRESSURE
FORCED DRAFT FANS
INDUCED DRAFT FANS
BAILEY CONTROL DRIVES
TEMPERING AIR
TEMPERING AIR BY REMOTE MANUAL OPERATION
HOT AIR BY MILL SUCTION
FORCED DRAFT BY STEAM PRESSURE & STEAM FLOW-AIR FLOW
INDUCED DRAFT BY STEAM PRESSURE & FURNACE DRAFT
TO PANEL

Fig. 7. Combustion Control System for pulverized coal fired boiler.

readjusted by steam temperature leaving the boiler. This arrangement permits the maintenance of a constant steam temperature over a wide range of loads.

With present day fuel costs, the cost of adequate instrument and control equipment for a boiler furnace can be expected to pay for itself in a short time by fuel savings alone. The improvement in public relations by the elimination of smoke will bring added dividends, as will the increased safety and reliability of the plant, and increased utilization of abilities of the operating personnel.

The day of proper instruments and automatic control on all industrial boiler furnaces is no longer ahead of us. It is with us now.

(Continued from Page 7)

Low Cost Sampler for Hydrogen Sulfide

hours with a maximum of 0.020 ppm. was observed. The maximum concentration found in this group of samples was 0.040 ppm.

It may be inferred from the continual recurrence of concentrations of the order of one to five parts per billion that they represent atmospheres whose primary effect is in the slow tarnishing of silverware.

While the development of the sampler was made primarily to serve as a useful tool in gaining factual information concerning sudden paint blackening episodes, these observations indicate that it may serve even more usefully in providing day-to-day information on the intensity of "silver tarnishing concentrations" for correlation with weather conditions and various industrial and domestic activities.

Cold Weather—Low Humidity

The sensitivity of the impregnated paper is materially reduced when the relative humidity of the air is low. This is true in winter when cold outdoor air is drawn into a sampler located in a warm room or in regions of naturally low humidity. In these circumstances, the air entering the sampler should be humidified. This is easily arranged by inserting in the sampling train, a small humidifying jar containing water at room temperature located either before or after the solids filter.

Acknowledgments

The work reported in this paper was carried out under a contract between the American Iron and Steel Institute and the Industrial Hygiene Foundation. Acknowledgment for the numerous mechanical improvements incorporated in the present instrument is due to the Research Appliance Company, Box 413, West View Road, Pittsburgh 9, Pennsylvania, who now manufacture the instrument.

Another Look At Reinjection of Fly Ash From Spreader Stokers

By W. C. Holton
Assistant Chief, Fuels and Air Pollution Division,
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The outstanding contribution of the spreader stoker to simplified and more flexible firing of coal has carried with it the well-known propensity for producing fly ash. That characteristic has been inevitable in such a system of suspension burning. Particles of ash and partly burned coal are carried through the furnace either to deposit in the boiler passes, on baffles, to be removed by dust collectors, or to pass out the stack. The small size of the particles and the velocity of air through the grates dictate that much of the suspended material cannot fall to the grate.

Fly ash has long been a problem, but one which is not peculiar to spreader stokers. The magnitude of the problem has naturally varied with the size of the units being fired. When spreaders were first installed on small boilers, the quantity of fly ash was of little consequence to plant operators. But now that spreader-fired boilers are being built to generate steam at rates as high as 300,000 lb. per hr., the weight of fly ash which must be handled becomes a major factor for the consideration of both the spreader manufacturer and for the plant operator. The disposal of fly ash can be a costly item; unlike grate ash, it is not suitable for land fill or for the other usual outlets for ash. It is usually without a market, and plant operators must contract to have it hauled away.

Reinjection

At some time in the early history of spreader installations, someone discovered that the carbon content of the fly ash was high enough that some method of reburning might be feasible. This was obviously the simplest, most economical disposal method; little pipework was required, and sufficient fan capacity or steam capacity to inject the fly ash was usually available. Thus, for the plant operator, the solution had been found.

It was realized, however, that this simple solution brought with it other problems. Adding more fine material to a furnace already burning fine fuel in suspension would certainly cause more dust to be emitted from the stack. In addition, some people thought that the extra loading of fly ash in the boiler would cause erosion of pressure parts.

To summarize, some air-pollution officials faced with a request to approve a spreader-stoker-fired boiler installation have decided that because the spreader stoker is well known as a producer of fly ash and because reinjection may increase dust emission, spreader stokers operating with reinjection should not be installed.

Inasmuch as few test data on this subject have been available, there can be little argument with the reasoning outlined above. Also, several papers have appeared in the technical literature in the last few years which substantiate this line of thinking. However, some experience with a spreader-fired unit indicates that reinjection can be practiced without exceeding the usual dust-emission limits. Thus, a re-examination of reinjection seems to be in order to bring forth all of the available facts so that air-pollution officials may have more complete information on which to base their decisions.

Systems for Reinjections

The few early accounts describing reinjection mention blowing the fly ash from the boiler hoppers through a pipe in the rear wall of the furnace. Either steam or air (usually from the overfire air blower) was used for reinjection. With the small boilers on which spreaders were first applied, only a few reinjection nozzles were used. When the units were built in larger sizes, it became evident that concentrating a large amount of fly ash in a few spots in the rear of the furnace would interfere with proper coal feeding and with even burning on the grate. Consequently, the trend shifted to the use of a large number of smaller reinjection nozzles spaced evenly across the rear wall of the furnace.

Stoker designers have usually tried to locate their reinjection nozzles as close to the grate as the boiler steelwork would allow, reasoning that the fly ash should be reinjected in a hot zone of the furnace to give the best conditions for burning of the material. Another design feature which probably developed with time was that of pointing the reinjection nozzles downward to counteract

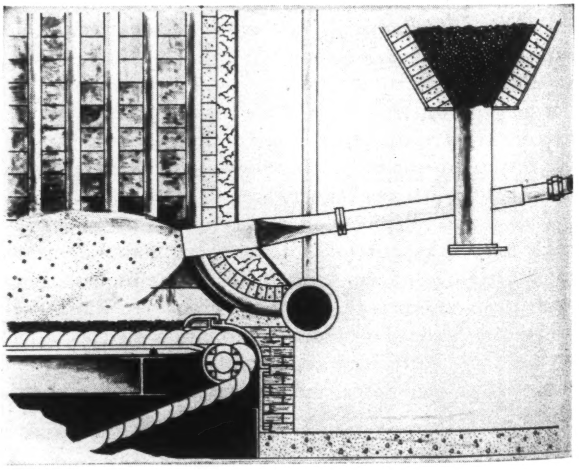

Fig. 1. Representative cinder pick-up and reinjection system.

the tendency of the fly ash to be swept upward immediately after entering the furnace.

Special steels are usually used for reinjection systems in order to resist the erosion of the fly ash. The nozzles, which are exposed both to the erosion of the ash and the heat of the furnace, may require special treatment in order to insure long life. Piping leading from the collection hoppers is kept to a minimum length and contains as few bends and elbows as possible, also to decrease erosion.

Figure 1 shows a representative cinder pick-up and reinjection system. In actual operation, particularly at high loads, the reinjected cinders burn like pulverized coal. Thus, the reinjection nozzle may act as a burner, and the flame which is produced is similar to that of pulverized coal burning. As shown in the drawing, some of the fly ash will fall to the grate and some will be carried upward by the undergrate air as soon as the fine fly ash leaves the reinjection nozzle.

A more recent method of reinjection brings the fly ash into the furnace by gravity. This is described in a paper by Morrow, Holton, and Wagner.[1] The theory behind this is that the initial velocity of the fly ash returned to the furnace by air prevents the fly ash from falling onto the grate. It was reasoned that, if the ash were deposited by gravity on the rear of the grate in a zone through which no forced air was admitted, the material might remain in the furnace longer and would possibly be more completely burned. The main advantage of this method would be to reduce dust loading. As will be shown later in this paper, this objective was achieved.

Mention should be made at this point of the relative merits of partial and total reinjection. Manufacturers and operators have long reasoned that a portion of the carbon loss in the fly ash could be recovered, and the dust loading increased only slightly, if only the coarse fly ash from the boiler hoppers were reinjected. The finer material from the collector hoppers would not be returned to the furnace. In a paper presented before the APCA several years ago, P. F. Best[2] outlined some of the advantages of partial reinjection. It should be noted, however, that there are not sufficient test data to permit stating an established conclusion on this point. As will be shown later, total reinjection may not always result in a dust loading at the stack which is in excess of the usual standards. Again, each plant should be judged individually on this point.

Review of Test Results

Air-pollution officials certainly cannot be blamed for regarding reinjection with a jaundiced view. Neither manufacturers nor users of spreaders have come forth with sufficient data to permit one to decide the question. On the other hand, it should be recognized that complete tests of the type required are seldom warranted on the part of either manufacturer or user. Complete boiler tests are expensive and time-consuming. Therefore, it is not surprising that so few data on the subject of reinjection are available. Several papers which have discussed complete tests can be reviewed, however, so that more facets of the problem can be viewed.

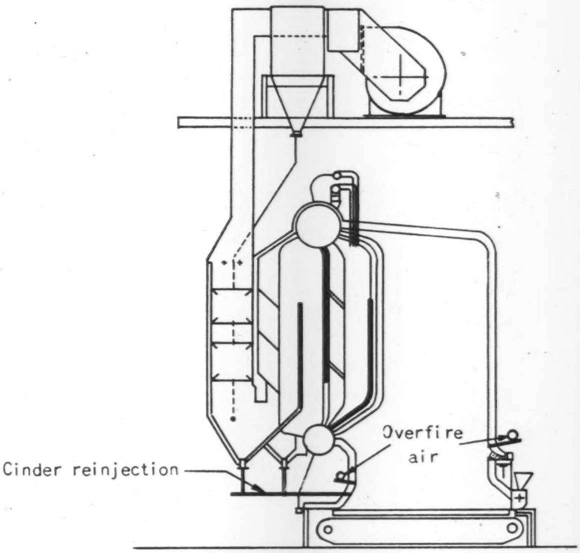

Fig. 2. Elevation of combustion engineering installation.

Tests Reported by Combustion Engineering

One of the first technical papers to publish data on reinjection was that of E. M. Powell.[3] This paper discussed reinjection from the standpoint of fly-ash erosion, and concluded that reinjection can increase efficiency but at the expense of increased maintenance costs. On the subject of dust loading, Powell noted that a number of smoke ordinances were in effect which limited dust emission to around 1 lb. per 1000 lb. of gas. Further, he states, "To meet such an ordinance when returning cinders from the dust collector to the furnace would require limiting the firing rate on the stoker to something less than 300,000 Btu per (sq. ft.) (hr.)". However, the data shown by Powell indicates that the units tested gave dust loadings of 1 lb. per 1,000 lb. or over for all tests, including those run without reinjection.

Figure 2 shows the unit tested by Powell. It will be noted that this is a two-pass boiler with economizer. Fly ash from the small boiler hopper is reinjected horizontally at a point above the spreader rotor. A conventional system of baffles is used in this boiler.

On the basis of the data shown in the paper, Powell derived an equation relating the amount of cinder being

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[1] Morrow, C. H., Holton, W. C., and Wagner, H. L., "Investigation of Gravity Reinjection of Fly Ash on a Spreader-Stoker-Fired Boiler Unit". Trans. ASME, *75*, pp. 1363-1372 (1953).

[2] Best, P. F., "What the Mechanical Type Dust Collector Industry is Doing to Meet the Various Problems Presented by Spreader-Stoker-Fired Water Tube Boilers", presented at the 45th Annual Meeting, Air Pollution and Smoke Prevention Association of America, Cleveland, Ohio, June 9-12, 1952.

[3] Powel. E .M., "Flv Ash from Stokers", ASME Paper No. 49-F-24, presented at ASME Fall Meeting, Erie, Pennsylvania, September 28-30, 1949.

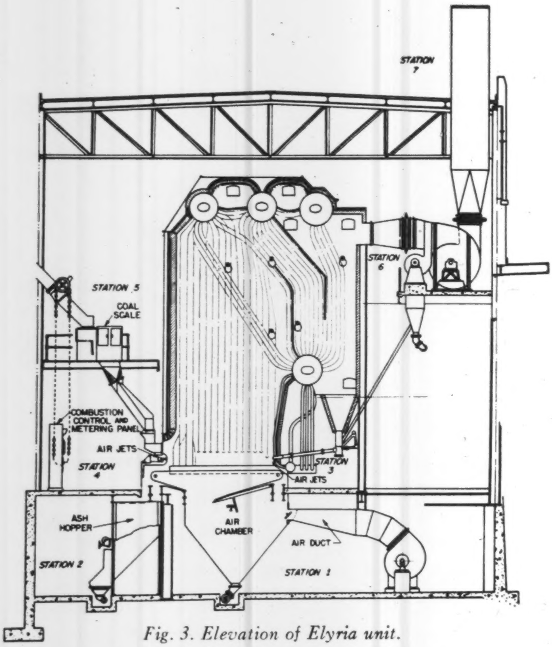

Fig. 3. Elevation of Elyria unit.

recirculated in the furnace to collector efficiency. The plotted curve indicated that an astronomical amount of fly ash would be constantly traveling through the furnace if a high-efficiency collector were used. However, these conclusions were based on data obtained on a unit using a collector having an efficiency of 80 per cent. Spreader-fired units currently being installed are usually required to use higher efficiency collectors. Also, the reinjection nozzles on the unit tested by Powell were located higher than is now common. Consequently, the data reported by Powell should be extrapolated to fit other cases only if the test conditions and the types of equipment used are comparable.

Elyria Test Results

An extensive series of tests on a spreader-stoker fired boiler furnace was sponsored by a group of spreader manufacturers in cooperation with Bituminous Coal Research, Incorporated. These were conducted in 1948 and 1949 at the Brown-Lipe-Chapin Division of General Motors Corporation in Elyria, Ohio. The results of these tests were summarized in a paper published in 1951.[4] These showed that partial reinjection decreased carbon loss from 2.3 to 4.1 percentage points, and that total reinjection brought a further decrease of 2.1 to 2.8 percentage points.

Figure 3 illustrates the boiler tested. This is also a two-pass boiler, but differs from that shown in Figure 2 significantly in the size of the boiler hopper. It will be seen that reinjection nozzles are below the level of the stoker rotors, and are pointed downward. Only two baffles are used in the boiler.

These tests showed that, at full load, it was possible to maintain a dust loading under that suggested by the ASME Model Smoke Law (0.85 lb. dust per 1,000 lb. gas corrected to 12 per cent CO_2) when operating without reinjection using a coal containing less than 30 per cent of minus ⅛-in. material. When operating with reinjection, only a coal containing less than 10 per cent of minus ⅛-in. material could be used if the code requirements were to be met. Thus, these tests indicated that a costly coal should be used on this unit. However, it should also be noted that a collector which had an efficiency of less than 80 per cent was used for these tests. Consequently, the results are again largely inapplicable to modern units.

Indianapolis Power and Light Tests

Results of some five tests on a modern spreader-fired installation were reported in 1951 by R. W. Gausmann[5]. Though the tests did not obtain complete data on reinjection, Gausmann did conclude that "about 3 per cent additional coal is required to carry full load on the boiler when reinjection of collector dust is discontinued". From the standpoint of dust emission, these tests were disappointing, for the author concluded that "it is difficult to maintain dust emission from the stack within reasonable values" when operating with total reinjection. He also noted that, had air heaters and economizers been installed with this boiler, much of the coarse dust might have been caught in the hoppers provided with these units. Thus, the collector in the Indianapolis installation may have been overloaded to the point that it could not function most efficiently.

Figure 4 shows the unit tested by Gausmann. This is also a two-pass boiler with a reinjection system practically identical to that shown in Figure 3. The boiler hoppers

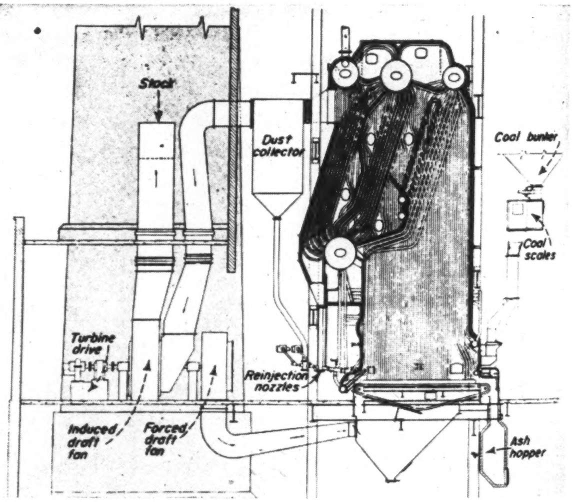

Fig. 4. Elevation of Indianapolis Power and Light unit.

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[4] Holton, W. C., and Engdahl, R. B., "Methods of Reducing Dust Emission From A Spreader-Stoker-Fired Boiler Furnace," Trans. ASME, *74*, pp 207-215 (1952).

[5] Gausmann, R. W., "Spreader Stokers Pass Rigid Load Tests With Flying Colors," *Power*, *95* (1), pp 78-81, 174, 175 (January, 1951).

seem to be smaller, however, and the system of baffles is quite different from that of the Elyria unit.

Tests Reported by Babcock and Wilcox

The most recent paper to touch on the subject of reinjection is that of Coykendall and Loughin[6], which was presented at the 1953 Annual Meeting of the ASME. Unfortunately, no determinations of actual stack emission were made during these tests. The authors conclude from the test data, however, that "either two-stage collectors or a highly efficient (93 per cent in this case) single dust collector is necessary on spreader-stoker-fired units in order to meet the requirements of the ASME recommended code on stack emission."

The authors also suggested the use of partial reinjection in order to minimize carbon loss and to avoid returning the fine fly ash from the collector to the furnace. It should be noted however, that in this installation the primary collector preceded the air heater and economizer. As noted earlier, Gausmann advocated using these units as auxiliary collectors ahead of the primary collector. Had this been done on the B & W test unit, the pattern of results and the conclusions drawn might have been changed.

Figure 5 is a side elevation shown in the paper by Coykendall and Loughin. This is a single-pass boiler without baffles. Although the reinjection system is not shown on this elevation, it is similar to that indicated in the previous two figures. It will be noted that the boiler hopper is quite large in comparison to those shown previously. In effect, these are double hoppers which are separated by a vertical divider to keep gas from bypassing the boiler-tube tank.

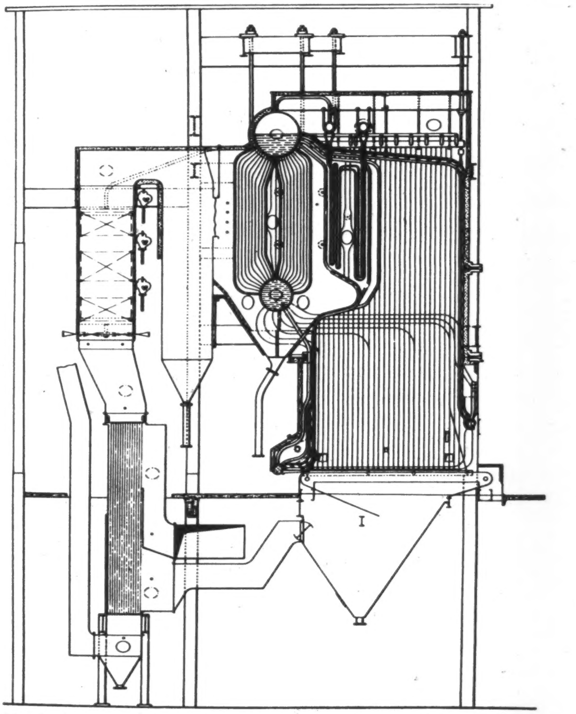
Fig. 5. Side elevation of modern Babcock and Wilcox spreader-fired boiler.

Tests of a Gravity Reinjection System

Another series of tests on a spreader-fired unit was conducted in 1950 under the sponsorship of the Detroit Stoker Company, the J. I. Case Company, and Bituminous Coal Research, Incorporated. These were reported in a paper by Morrow, Holton and Wagner[1] which was published in 1953. This unit was somewhat different from those mentioned previously in that an air-heater and economizer preceded the dust collector. A high-efficiency multi-tube dust collector was used. Most important, fly ash from the collector was returned to the furnace by gravity onto a dead zone in the rear of the furnace as described previously. For the test program, it was arranged to conduct complete boiler tests while operating under the following conditions:

1. No reinjection.
2. Reinjection of only the coarse cinders from boiler and economizer hoppers by air, while discarding collector fly ash.

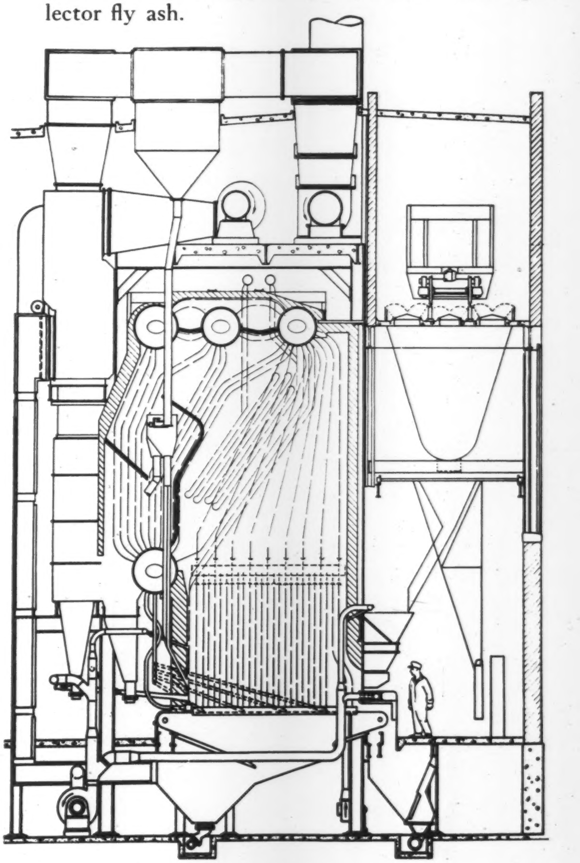
Fig. 6. Elevation of boiler tested at the J. I. Case Company.

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[6] Coykendall, L. H., and Loughin, P. R., "Boiler and Furnace Designed for Spreader-Stoker Firing," ASME Paper No. 53-A-136, presented at the ASME Annual Meeting, December, 1953.

3. Reinjection of boiler and economizer cinders by air and collector fly ash by gravity.
4. Reinjection of all fly ash by gravity.

Figure 6 illustrates the Case installation. Again a two-pass boiler is used, with cinder-reinjection nozzles located low in the rear wall and pointed down. Nozzles for gravity reinjection of fly ash from the collector are shown entering the rear wall of the furnace above the normal reinjection nozzles. Supporting steelwork prevented placing these nozzles in a more favorable location closer to the grate.

These tests showed that some 63 per cent of the carbon in the fly ash was recovered when operating with total reinjection. With regard to dust emission, the stack loading when operating with total reinjection was only 0.30 lb. dust per 1,000 lb. gas. A number of factors contributed to this low dust loading; some of these were:

1. Low excess air
2. Low exit-gas temperature
3. Minimum air infiltration
4. High-efficiency dust collector
5. Complete automatic control

Erosion of Pressure Parts

Although air-pollution officials are not necessarily concerned with the possible erosion of pressure parts which may be accelerated by reinjection, the subject of reinjection cannot be divorced from that of erosion. It was noted previously that Powell pointed out the dangers of erosion associated with reinjection. Powell also notes that reinjection also causes a reduction in heat-transfer efficiency from the greater ash accumulation on the heating surfaces and increased maintenance of the furnace walls due to increased slagging.

A slightly different point of view was expressed by W. S. Blundin[7] in a discussion on the results of the Elyria tests. Blundin noted that the scrubbing action of fly ash has caused failure of pressure parts, but added that this action does serve to keep heating surfaces clean. Blundin suggested that erosion may be checked by designing for low gas velocities, using a single-pass boiler, and using a cinder-catcher baffle. In another paper, Andrews and Hawley[8] also suggested that overfire air be used to reduce carry-over and thus reduce the possibility of erosion.

The beneficial effect of fly ash scrubbing the heating surfaces is noted by Gausmann, who reports that no soot blowers were installed in the Indianapolis Power and Light unit, and that satisfactory operation was being obtained without blowers. This was confirmed by the experience on the J. I. Case unit. Three boilers of the type tested at Case are in service at various plants of this company and have been operating for a total of 13 years without trouble from erosion. This would indicate the importance of the integration of the design of stoker, boiler furnace, and baffles in order to minimize the possibility of erosion.

Boiler Design

A careful study of the figures which have been presented will indicate that the design of boiler baffles and hoppers may have a significant effect on fly-ash emission. Boiler hoppers should act as low-draft-loss collectors, and should be so designed. Baffles should be so placed that changes in direction of gas flow will cause fly ash to fall into the hoppers, yet must be carefully designed to minimize the possibility of erosion.

Certainly too little is known about the effect of boiler design on dust emission. The figures shown indicate that boiler manufacturers are well aware of this, and are trying new designs in an attempt to utilize the fly-ash-collecting abilities of the boiler to the highest degree.

Conclusion

From the standpoint of the manufacturers and users of spreader stokers, reinjection in some form is "here to stay". In the continuing struggle to attain higher operating efficiencies, at least a portion of the carbon loss represented by the fly ash must be regained. However, plant operators recognize their responsibilities in meeting local air-pollution ordinances and desire to keep within these ordinances as well as to operate at the highest possible efficiency.

The published data on reinjection have, for the most part, shown that reinjection has increased dust emission beyond code limits. However, some of these data have been obtained on units equipped with low-efficiency dust collectors. In other cases, stack-emission rates have been obtained by calculation using an assumed collector efficiency rather than by actual test.

In the past few years, experience of boiler manufacturers has led to the construction of units specifically designed to minimize fly-ash erosion. More attention has also been given to the design of boiler hoppers which serve as efficient low-draft-loss dust collectors. At the same time, spreader manufacturers have sought to reduce air infiltration and to lower excess air. New methods of reinjection have also been studied in an attempt to reduce fly-ash emission.

Results of the tests at the J. I. Case plant show that these new ideas can permit total reinjection while maintaining an allowable dust emission. The modern design of this plant has paid dividends in increased efficiency and ease of operation.

The examples shown here will indicate that air-pollution control officials should give thorough consideration to any possible spreader-fired units. The data on reinjection are not sufficient to permit a blanket ruling for or against total reinjection. Each new installation should be judged on its own merits. If possible dust loadings on new units are to be predicted from published test results, one must be certain that the units are similar in all major respects.

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[7] Blundin, W. S., discussion of paper of Reference 4, Trans. ASME, *74,* pp 215, 216.

[8] Andrews, L. V., and Hawley, C. F., "Fly Ash Erosion in Boilers," ASME Paper No. 49-F-22, presented at ASME Fall Meeting, Erie, Pennsylvania, September 28-30, 1949.

Factors in the Design and Operation of Industrial Dust Collectors as Related to Air Pollution

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A reduction in the general level of atmospheric pollution by suspended solids originating in power plants on industrial operations is primarily dependent upon the average effectiveness of dust collector installations as well as the relative number of such installations with respect to the total dust sources in a given area. As more plants put in dust collecting equipment, we have reason to expect a general improvement in the cleanliness of the surrounding atmosphere and this is found to be true particularly in areas under the jurisdiction of an Air Pollution Control Authority or an active civic group. However, it is believed that further improvements are possible if the effectiveness of all dust collector installations be maintained at their maximum. Our dust control ordinances specify a limit on the allowable emission and we usually implement them by perhaps a test at the time of initial installation or acceptance of the manufacturers guarantee. This, of course, establishes compliance with the existing regulations and is a great advance toward our ultimate goal, but unless we maintain such installations at their expected level of efficiency we have not made the gain that the record would indicate. At this point, we would like to emphasize that we have no thought whatsoever of any attempt at the impossible task of continuous policing. By contrast to visual checking, to insure compliance with the smoke regulations, any endeavor to check solids discharge on a comparable scale would be impractical. If an indicating instrument were available to measure dust loading with the same facility that we measure temperature with a thermocouple such a course might be possible, but we are all familiar with the difficulties and time involved in making such a determination at the present stage of the art. We must therefore depend on education of the user of dust collector equipment, as to the importance of the several phases of the dust collection problem, as they may affect the degree of pollution of the surrounding atmosphere.

We can consider that there are three phases to the problem. The first of these has to do with the basic design of the dust collector; the second, the specification of the particular conditions and requirements and the proper selection of the equipment most suited to these specifications and the third phase deals with the continued operation of the equipment at its highest level of effectiveness.

The basic design of dust collectors is a subject too vast to discuss in detail in this paper and to the user of collectors would be only of academic interest. However, there are some general principles with which he should be familiar.

It is fundamental for a given dust collecting problem that the total cost of the installation, which includes capital investment and operating expense, will vary directly with the efficiency required. If for the moment we consider cyclone collectors, we find that an increase in efficiency is obtainable by modification of cyclone proportion at the expense of additional pressure drop and/or an increase in the size of the cyclone. The latter is not a contradiction of the popular concept that efficiency increases with decreasing diameter but rather points up the fact that while fundamentally a cyclone of given proportions will be more efficient as its diameter is reduced, it may be much less efficient than another cyclone of five times its diameter but which utilizes a more effective shape. Such a cyclone would of course be even more efficient in a comparable diameter but its volumetric size would be greater.

The cost of an electric precipitator will increase with an increase in required efficiency. In this case, the additional cost is primarily in the capital investment, the operating cost in any case being a nominal part of the total. Other types of dust collectors will have a similar cost-efficiency relation with the possible exception of devices which use the filtering principle in their operation.

It is evident then that the specification of efficiency will determine in large measure the cost of the installation. In addition, the type of equipment will affect the cost and it is important in selection that the most effective equipment or combination of equipment be utilized for the conditions involved.

Equipment Selection and Installation

Fundamentally, there are two basic reasons why dust collectors do not function as planned, even though the operation of the equipment by the operators is sound and these reasons are:

1. Improper selection of equipment.
2. Poor duct design.

Selection of equipment for a specific application is, of course, an economic problem. It goes without saying that almost any degree of dust collection can be obtained, for example on a boiler installation, the flue gas could be passed through several stages of mechanical collectors, thence through a 99% electric precipitator, then a bag filter and finally a wet scrubber. No doubt stack appearance would be excellent, but obviously the installation and operation cost as well as the space requirement would be unreasonable and prohibitive. Improper selection of equipment, of course, means that collectors of too low an efficiency have been selected for too fine a dust; or in the case of electric precipitators, the electrical capacity of the precipitator is not suited to the electrical properties of the dust. The responsibility for a situation of this sort is difficult to determine, but it would not be unfair to place a large part of the responsibility on the fact that the purchase specifications sometimes do not accurately reflect the actual plant condition. The dust collector manufacturer makes the recommendations on the basis of information supplied, recommends minimum equipment which will do a satisfactory job. The reasons for this are obvious, (as mentioned before) units of overly high performance are expensive in terms of initial investment, space and power consumption, and on the basis of the vast majority of purchase specifications, the higher cost of such units is not justifiable. Then, too, there is the question of competition; no manufacturer would jeopardize his competitive position by offering equipment which is more efficient than required by the specifications and hence too expensive. Fortunately for the communities, the dust abatement officers, the general public, and incidentally, fortunately for the dust collector manufacturers, too, the purchase specifications submitted to the latter are very nearly always accurate, and the equipment offered and supplied does an adequate, if not excellent job, provided, of course, that the equipment is properly installed and operated. It is only in those few cases where initial data is incorrect or inadequate that collector performance may not come up to expectations on an overall efficiency basis, although the collector might be operating at its anticipated performance with respect to the collector's fractional efficiency. In the case of the mechanical dust collector, if the actual dust handled is much lighter or has a preponderance of very fine particles, or in other words has a much lower settling velocity than originally anticipated for that particular installation, then overall efficiency will suffer and stack emissions will increase. The only way of handling a problem of this sort is to make doubly sure that original purchase specifications are accurate, or if it is impossible to obtain accurate data, then it behooves the purchaser of dust collectors to be very conservative in the specification of equipment. It is frequently better to over design an installation, rather than to purchase the least expensive equipment available, only to be forced to eventually replace this with better equipment to meet a dust ordinance.

Another important consideration, the effect of gas volume on performance is discussed later on in this paper. Suffice it to say at this time that for a mechanical collector an increase in collector gas volume over specifications will result in an imperceptible increase in collection efficiency, and a considerable increase in pressure drop through the collector while a decrease in volume will result in somewhat lower efficiency and pressure drop. For an electric precipitator any increase in gas flow over design will result in a decrease in collection efficiency.

On the question of duct design, it can safely be said that more, otherwise excellent, installations have been rendered ineffective due to poor inlet connections than for any other reason. An excellent paper was presented last year by the Koppers Company on the effects of a poor inlet condition on an electric precipitator installation and the manner in which it was cured. Therefore, this paper will not delve into the inlet problems of electric precipitators, but will deal only with some of the problems of ducting encountered with mechanical dust collectors. Ideally, there should be about five equivalent pipe diameters of straight duct work before the inlet of the dust collector. In practice this seldom, if ever, occurs, and it therefore becomes necessary to design and install duct work, which will get the dust laden gas to the dust collector inlet with a minimum effect on collector performance. In the interest of proper collector performance, the manufacturer is extremely interested in the type of inlet connection the purchaser intends to furnish on the dust collector; indeed, it would be highly desirable if every purchaser of dust collecting equipment would submit his proposed duct work to the dust collector supplier for comments, prior to finalizing the design of these ducts. In this way any obvious fault of the duct design, purely from a dust collection point of view, could be eliminated. It is not intended here that the dust collector manufacturer design the duct work for a customer, the purpose is only to guide the customer's design in the proper direction so that the collector performance will not be adversely affected by something in the duct design which might

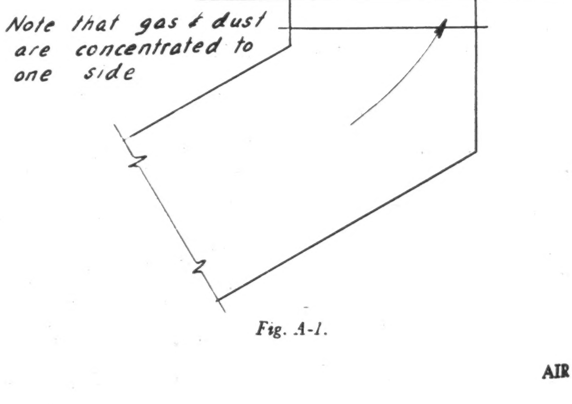

Fig. A-1.

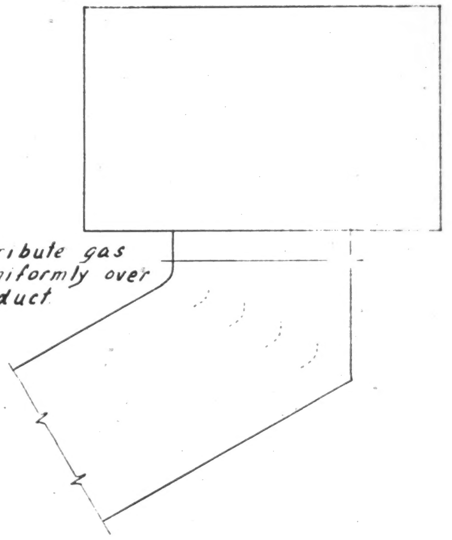

Fig. A-2.

have been avoided. It is regrettable and disheartening to know how few purchasers of dust collector equipment pay the proper attention to duct design, and how few consult the supplier on the proper installation of the equipment.

It is always desirable to avoid bends at the collector inlet, particularly if these bends come from the left or right. As seen on the Figure A-1, a gas stream entering a mechanical collector from the left will cause the largest mass of gas and dust to be handled by the individual cyclones or tubes on the right (or opposite) side of the dust collector. These individual units, by handling a higher proportion of the gas, will incur a higher draft loss and a lower static pressure at the individual units' cone or tube outlet. This in turn creates a recirculation between those units handling a lower volume of gas and those handling a higher volume of gas, and dust collector performance will suffer, with particularly high losses in the very fine particle size range, i. e., those particles which are more apt to be influenced by the gas, rather than inertial laws. Naturally, the greater the number of individual units serviced by an individual hopper, the greater this problem becomes, and the more apt it is to occur. One method of overcoming this is the use of turning vanes, as shown on Figure A-2. These are effective, and in fact reduce draft loss across the bend, but suffer from the fact that they are subject to erosion, and hence frequent maintenance, and also due to the fact that some dusts tend to build up on their surfaces. Therefore, vanes of this type can only be recommended where the dust is not abrasive and does not have a tendency to build up and pack on a surface.

Where it is impractical to install vanes due to the characteristics of the dust, it is usually possible to rearrange the installation to minimize the effect of poor approach conditions.

Operation of Dust Collection Equipment

No matter how well designed a dust collector may be, nor how admirably it may be suited to a particular instal- nor how admirably it may be suited to a particular instal- lation, it cannot possibly do a satisfactory job of dust rectly operated. All too often, an excellent dust collector is allowed to perform in an inefficient manner because of faulty operation.

This, to some degree, is understandable because every plant is primarily concerned with the manufacture of a product, be it cement, limestone, paving material, or electricity. All equipment affecting production is carefully maintained and operated for maximum output. However, when installed for air pollution abatement, a dust collector has no direct effect upon plant output, and its operation and maintenance is apt to be of secondary consideration.

Let us first consider the operation of that simplest of all types of dust collectors—the cyclone. In general, there are only three major items which need be checked in order to insure maximum collection efficiency in a cyclone. These are:

(1) The cyclone should handle the volume of gas for which it was designed. Naturally, the basis of collection efficiency in a cyclone is the centrifugal force which is impressed upon the dust particles. If the gas velocity through the cyclone is less than for which it was designed, the centrifugal force exerted upon the dust particles will be reduced and the collection efficiency will be lower than was anticipated.

In the vast majority of installations, the cyclones are correctly sized for the gas volume at the time of installation, and the cyclones work efficiently. However, very often, changes occur in methods of production in a particular plant, and gas quantities and/or temperatures may change without reappraisal of the dust collector installation. In cases where the gas volume has decreased appreciably, it is essential to reduce the collector capacity, if best efficiency is to be maintained. Since most cyclone installations consist of multiple cyclones arranged in parallel, it is usually quite simple to blank off one or more cyclones, thus maintaining the required velocity in the remaining cyclones.

(2) The second major cause of operating difficulty in a cyclone installation is the leakage of air into the dust hopper. Most cyclones are installed before a fan (in order to protect the fan wheel from abrasion), and consequently the static pressure in the dust hopper is below atmospheric pressure. Any air that might leak into the dust hopper will flow up the cyclone vortex entraining dust which has already been collected by the cyclone. The greater the leakage, the more dust will be lost, with the loss consisting chiefly of the finer particles. Therefore, if the hopper is not properly sealed, outside air will leak into the hopper and decrease the collection efficiency of the cyclone.

In this connection, we would like to relate an experience of one of our field men, which while not commonplace, nevertheless illustrates this problem as well as the necessity for continuing supervision of the dust collector operation.

Some years ago one of our servicemen visited a plant in response to a complaint. Upon arrival he found at first glance that the complaint was justified, there was dust all over the plant and the neighborhood. Our man inspected the collector installation and found the hopper valve tied open, with a veritable gale of air sweeping into the bin. Only a very few pounds of dust had managed to fall through this air blast into a wheelbarrow which was resting below the hopper. The rest of it was being swept up through the cyclone and induced draft fan and finally discharged from the stack. Our man questioned the laborer whose job it was to empty the dust hopper into the wheelbarrow and cart away the dust. It developed that he was quite proud of his idea of tying the hopper valve open. Before he discovered it, he had been spending most of his time pushing wheelbarrow loads of dust to the dump, but with his new system he was able to comply with his orders to keep the hopper empty at all times and yet only make one trip a day to the dump with the wheelbarrow. He was rather disappointed when told that the valve would have to remain shut.

(3) The third major factor which can reduce the collection efficiency of cyclone collectors is overfilling of the dust hopper. A dust hopper, like any container, can only be filled to its top, and then it must overflow. In the case of a cyclone dust hopper, the overflow, of course, is discharged thru the stack. The cyclone dust hopper, however, cannot even be filled to its top but only to a given level, dependent on the type of cyclone above which level dust is picked up by the cyclone vortex and discharged to the atmosphere. It is possible to fill the hopper still further, but the collection efficiency will continue to decrease until a point is reached where the efficiency is zero and no more dust can be stored in the hopper.

Some few plants have been encountered which allowed the hopper to fill completely causing collection to cease entirely, but it is more common to find the collection efficiency periodically impaired to some degree by allowing too much dust to accumulate in the hopper. This can be easily avoided by increasing the emptying cycle from, say, once a shift, to twice a shift. The difficulty is, however, that the exact amount of dust collected is seldom realized. For this reason, it is necessary for dust collectors to be equipped with an adequate dust withdrawal system.

Before we leave the question of cyclone operation we might mention in passing, a few of the less comomn operating problems sometimes encountered.

Leaks that might develop in the equipment should be repaired, and any interior work that might be necessary should be done to maintain the original smooth contour.

The collectors should be insulated when handling a moisture laden gas near its dewpoint.

All foreign objects such as planks, overalls, and lunch buckets, should be removed from the collector before starting up. (This is not nearly so rare an occurrence as might be imagined).

Thus we see that in spite of their simplicity, cyclone dust collectors still must be correctly operated in order to function properly.

The electric precipitator is a different "type of animal" from the cyclone, and requires more careful maintenance. It is impossible in the short time allotted to discuss all aspects of precipitator operation, but we might cover some of the high points.

All personnel concerned with the operation and maintenance of electric precipitators should read and understand the manufacturers instruction manual and operating instructions. To insure that all operating personnel thoroughly understand the equipment, it is advisable to give individual instruction in the performance of all normal and emergency operations of the precipitator equipment. It should always be remembered that, in most cases, an electric precipitator is uniquely designed for a specific job, and its operation is not necessarily the same as any other precipitator, even if in the same plant.

In operation, the collection efficiency of a precipitator can be decreased by many operational factors. Needless to say, the dust hopper should be free from leaks and must not be overfilled, just as with cyclones. In addition, the precipitator should not be expected to handle more gas than that volume for which it was originally designed, without sacrificing some efficiency.

Relatively minor changes in plant processes or methods may change these properties of the gas or dust related to precipitator performance to a major degree, and necessitate readjustment of the precipitator operating level.

All electrical instruments readings should be routinely observed and recorded. Any sudden deviation from normal may indicate an abnormal condition in need of correction. In this connection, it should be noted that the inability to hold the design voltage on the precipitator without excessive electrical short circuits might be due to a reduction in the electrical clearance at some point in the precipitator. In this case the precipitator can, of course, be operated at a reduced voltage, but only at some sacrifice in collection efficiency. The proper procedure should be to correct the condition as soon as possible and continue to operate the precipitator at its design voltage. There are a number of factors which might cause the condition just described. A build-up of sticky dust on the collecting electrodes might occur during a succession of equipment start-ups and shut-downs. An emitting electrode wire might have broken and tangled within the precipitator. Or, more seriously, the entire precipitator may have become misaligned due to settling of the foundation or uncompensated thermal expansion. These latter faults, however, can usually be prevented by good initial design.

(Concluded on page 39)

Factors Affecting Dust Collector Efficiency

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During the past ten years considerable progress has been made in the field of dust collection. Dust collector manufacturers are continually working on the improvement of their respective collectors, and trying to create new devices with higher efficiencies. However, very little has been done in the way of cooperation between manufacturers, to aid the customer in evaluating the claims made for different collectors, and selecting the one best suited for his requirements.

It happens that our company is an old timer in the fan industry, and a comparative new-comer in the dust collector field. It is quite apparent to us that there is a confusion of tongues in the dust collector industry, which does not exist in the fan industry. The principal reason for this, in our opinion, is the difference in the type of test codes available in these two fields.

In the fan industry we have the N.A.F.M.(1) code and the A.S.M.E.(2) code. Both of these are laboratory test codes for determining the performance of centrifugal fans over their entire operating range. They include explicit rules for conducting the test, rules for plotting performance curves under the test conditions, and formulas for calculating the performance with any variation from test conditions. With a fan performance curve, or capacity table, and a copy of either code, the engineer or user can calculate the performance under any conceivable combination of operating conditions. These codes have been accepted throughout the industry, and provide a common language for all parties interested in fan performance.

The dust collector industry does not have a code of this type. We do have the A.S.M.E.(3) test code for Dust Separating Apparatus, but this is not a rating test code. It is a field test code, designed for one purpose only, to determine the performance of a collector under the conditions which happen to exist in a specific installation. It does not attempt to predict the performance of the same collector under any other set of conditions, or to formulate rules for calculating such variations. Without a code of the N.A.F.M. type, to establish a common language and procedure, it is not surprising that much confusion exists regarding the effect of varying conditions on dust collector performance.

All manufacturers present fractional efficiency curves, based on tests under certain controlled conditions. Operating conditions vary widely from the test conditions and it is necessary to make corrections for these variations. Without an official code covering these variations, each manufacturer has had to devise his own rules. Naturally, with each manufacturer working independently, there is a wide variation in the methods used. As a result, it is difficult for the customer to evaluate the performance of competing collectors under his specified conditions, or to calculate the performance if, as frequently happens, actual operating conditions differ from those specified.

A presentation of the methods used by one manufacturer may help to clarify this situation. This presentation applies to one particular collector, the Aerodyne. However, the basic principles involved would apply to any mechanical collector.

There are four groups of variables which influence dust collector performance. They are:

1. Dust variables
2. Fluid variables
3. Operational variables
4. Collector variables

Dust variables are size, shape and weight of dust particles . These are functions of the three linear dimensions and particle density.

Fluid variables are density and viscosity. These are functions of air or gas composition, temperature, and barometric pressure.

Operational variables are gas velocity through the collector, or capacity in cubic feet per minute, and dust loading, generally expressed in grains of dust per cubic foot of gas.

There are an infinite number of collector variables. With a collector of given design, the cumulative effect of all this group determines the shape of the fractional efficiency curve.

The effect of dust and fluid variables can be simplified by using the terminal velocity theory. Terminal settling velocity, commonly called terminal velocity or settling velocity, is the velocity of a particle, falling in still air or other fluid, after a condition of uniform motion is reached. Terminal velocity and mechanical collector performance are both controlled by the same dust and fluid variables. Therefore, terminal velocity is a very useful function for coordinating the variables involved in dust collector work.

For the range of application in which we are interested, terminal velocity follows Stokes' law:

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[1] "Standard Test Code for Centrifugal and Axial Fans", National Association of Fan Manufacturers, Inc.

[2] "Test Code for Fans", The American Society of Mechanical Engineers.

[3] "Test Code for Dust Separating Apparatus", The American Society of Mechanical Engineers.

$$(1)\ V = \frac{g\ L^2\ (d_p - d_f)}{Kn}$$

Where V = terminal velocity
g = local acceleration due to gravity
L = a linear dimension of the particle
d_p = density of particle
d_f = density of fluid
n = viscosity of fluid
K = a constant

With any particle which is not a perfect sphere, K has an infinite number of values, depending upon the shape and orientation of the particle. For a perfect sphere, equation (1) becomes:

$$(2)\ V = \frac{g\ D^2\ (d_p - d_f)}{18\ n}$$

Where D = diameter of solid sphere.

If the fluid is air, or other gas commonly encountered in dust collector work, d_f is insignificantly small compared with d_p. Therefore, for determining dust collector performance, or for dust classification by air elutriation, d_p may be substituted for $(d_p - d_f)$ in equations (1) and (2). However, for dust classification by liquid sedimentation $(d_p - d_f)$ must be used.

With the commonly used mixture of English and metric units, the Stokes' law equation for solid spherical particles settling in 70°F. air becomes:

$$(3)\ V_{70} = .072\ D^2 d_p$$

Where V_{70} = terminal velocity in 70°F. air, inches per minute.
D = particle diameter, microns
d_p = particle density, grams per cubic centimeter

Actually the particles are seldom solid spheres. However, if the terminal velocity and particle density are known, a theoretical diameter can be calculated by solving equation (3) for D:

$$(4)\ D_t = 3.73 \sqrt{\frac{V_{70}}{d_p}}$$

Where D_t = theoretical diameter, or diameter of a solid sphere, of density d_p and terminal velocity V_{70}.

Particle diameters obtained by sedimentation and elutriation are really theoretical diameters, not actual diameters, unless the particles happen to be solid spheres and are all of the same density.

Another commonly used value is the equivalent particles diameter, or diameter of a solid spherical particle of unit density, having the same terminal velocity as the particle under consideration. The formula for equivalent diameter, derived from the Stokes' law equation is:

$$(5)\ D_e = D_t \sqrt{d_p}$$

Where D_e = equivalent diameter of solid spherical particle of density 1.0 g/cc

So it appears that we have three diameters to consider. Before discussing how they are used, it would be advisable to discuss briefly how they are determined.

Terminal velocity in air can be determined directly by air elutriation, or similar methods, such as the Roller Elutriator,(4) or the Bahco Micro Particle Classifier. These instruments may be calibrated to give D_e direct, or D_t may be calculated from terminal velocity. If D_t is desired, specific gravity must be determined, and D_t calculated from terminal velocity or D_e. In dust collector work, a specific gravity determination is not necessary with elutriation, because the value we are really interested in is D_e.

Terminal velocity in a liquid can be determined by sedimentation. Specific gravity must also be determined, to permit calculation of D_t or D_e in air. With nonhomogeneous dusts, this introduces an error, as shown by the following example.

Fly ash consists of a heterogeneous mixture of various compounds, with widely varying particle densities. Average specific gravity is normally between 2 and 2.5. However, some particles may have a density as low as 1.3 or as high as 5.2.

Assume a fly ash sample of average specific gravity 2.3, containing some particles of 1.3 density and some of 5.2 density. Assume a fraction of this sample of average D_t = 10 microns, determined by sedimentation in a liquid of 0.8 specific gravity. Calculating the diameters corresponding to these densities by Stokes' law formulas we obtain:

Particle Density, d_p	2.3	1.3	5.2
D_t for same V in liquid	10	17.3	5.83
$D_e = D_t \sqrt{d_p}$	15.2	19.7	13.3
% Error in D_e	0	−22.8	+14.3

If the same sample is classified by elutriation in 70° air, we obtain:

Particle Density, d_p	2.3	1.3	5.2
D_t for same V in air	10	13.3	6.65
$D_e = D_t \sqrt{d_p}$	15.2	15.2	15.2
% Error in D_e	0	0	0

From this comparison it appears that sedimentation is not as accurate, for our purposes, as elutriation. However, the example cited is an extreme case, so we consider liquid sedimentation an acceptable method.

Another commonly used method is microscopic analysis,(5) supplemented by a specific gravity determination. By this method another diameter which we will call D_m is determined. D_m is an attempt to approximate the actual theoretical diameter of the particle. Generally, the projective area is determined, and the diameter of a sphere of

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[4] Foley, R. B., "Terminal Velocity as the Measure of Dust-Particle Characteristics". Transactions American Society of Mechanical Engineers, Vol. 69, pp 101-8, 1947.

[5] "Analysis by Microscopical Methods for Particle Size Distribution of Particulate Substances of Subsieve Sizes", ASTM Designation E20-51T, American Society for Testing Materials.

the same projective area is calculated as D_m. There are four possible sources of error in this method, that is:

Errors in determining D_m of a three dimensional particle from a two dimensional image.

Errors in assuming that D_m is equivalent to D_t.

Errors in converting particle count to percentage by weight, with a non-homogeneous sample.

Errors due to variation from the mean specific gravity. For the sample used in previous examples, the range of this error would be:

Particle Density, d_p	2.3	1.3	5.2
D_m	10	10	10
$D_e = D_m\sqrt{d_p}$	15.2	11.9	22.8
% Error in D_e	0	+33.3	−33.3

Evidently, for determination of terminal velocity, or equivalent diameter, microscopic analysis is much less accurate than elutriation or sedimentation. In fact, the possibility of error is so great that we do not consider it acceptable as a basis for predicting collector performance.

A fourth method is sieve analysis. This has no practical application with the type of collectors discussed in this paper. It does not cover the range we are interested in.

To avoid misunderstandings, we would like to emphasize that this discussion of dust classification is based on a collector which subjects the dust particle to centrifugal and aerodynamic forces. The statements made may not apply to electrostatic precipitators, bag collectors, or other collectors utilizing other forces. These statements certainly do not apply to process control work, where actual particle size is the end result required. Microscopic analysis is, without question, the most accurate method for determining actual particle sizes in the subsieve range. But we are not interested in actual particle size. We want to know how the particle is going to behave in the collector.

Having determined the analysis of the dust, in terms of terminal velocity, or equivalent diameter, or theoretical diameter, how is the collector performance determined? Fig. 1 shows a fractional efficiency curve of one type of Aerodyne collector, under certain specified conditions of capacity, temperature and dust loading. This curve is based on a number of laboratory tests with dusts of known terminal velocity.

This particular curve is plotted against equivalent diameter. A similar curve could be plotted against terminal velocity. We selected equivalent diameter for two reasons. Equivalent diameter is more easily visualized by the occasional user. Also, equivalent diameter is a function of the dust variables only, whereas, terminal velocity is a function of dust and fluid variables.

Fig. 1 also includes a chart for converting theoretical diameter, D_t at specified density, to equivalent diameter, D_e at unit density. The chart and curve can be used to calculate the overall efficiency of this collector, with any specified dust analysis, and particle densities from 0.5 to 10 g/cc. If particle density is not known, specific gravity may be used, bearing in mind that this may introduce an error with non-homogeneous dusts.

This efficiency curve is plotted at rated capacity, with 70°F. air, and dust loading 2 grains per cubic foot. For capacities higher or lower than rated, flue gas temperatures above 400°F., or dust loadings above 3 grains per cubic foot, correction must be made for the operational and fluid variables.

For capacity correction, Table I gives the rated capacity in CFM of standard size Aerodyne cones. Fig. 2 includes a correction curve for variations from rated capacity, calculated from extensive laboratory tests. For temperatures below 400°F. multiply CFM per cone by number of cones to obtain rated capacity of collector. Divide actual, or specified, capacity by rated capacity, and multiply by 100 to obtain % of rated capacity. Read particle diameter factor from lower curve, Fig. 2.

TABLE I

RATED CAPACITIES OF AERODYNE CONES

Cone Size	15—3/4	17—3/4	19—3/4	22	24—3/4
CFM per cone	4,600	5,900	7,300	9,000	11,500

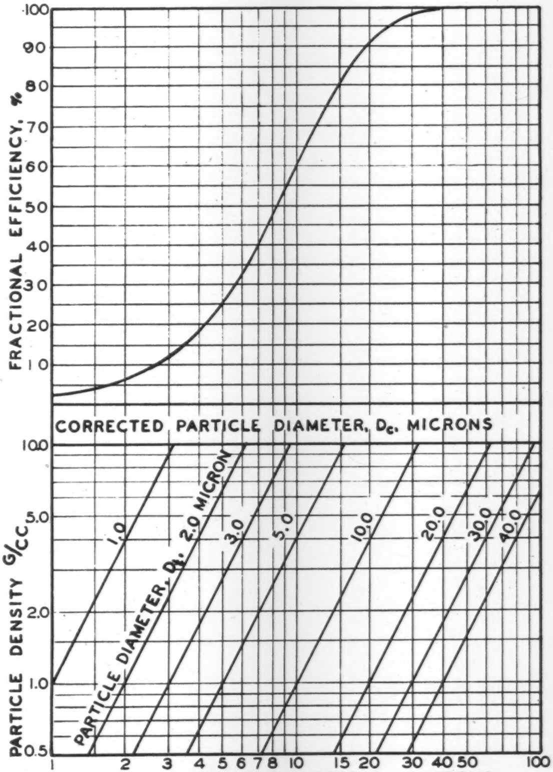

Fig. 1. Efficiency chart—type C Aerodyne at rated capacity, 70°F. air, dust loading 2 grains per cubic foot.

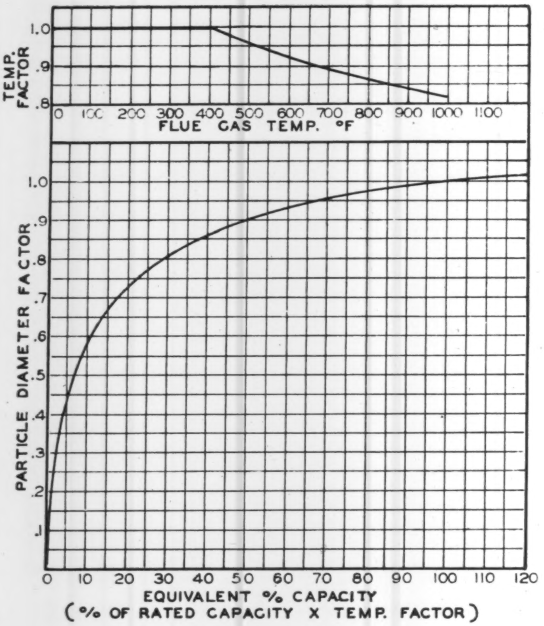

Fig. 2. Correction factors type C Aerodyne.

Multiply equivalent diameter, D_e, by this factor to obtain corrected diameter D_c. Read fractional efficiency, corresponding to D_c from Fig. 1.

Fig. 2 also includes a curve for temperature correction. This curve is based on the influence of the fluid variables

In the Stokes' law range, the effect of fluid density is insignificant, and terminal settling velocity varies inversely with viscosity. Gas viscosities increase with temperature, so terminal velocity and collector efficiency go down as the temperature goes up.

To evaluate temperature effect we have to consider the behavior of a particle in a centrifugal field. The equation for this is:

$$(6)\ V_e = V \frac{V_t^2}{Rg}$$

Where V_e = centrifugal terminal velocity
V = terminal settling velocity
V_t = tangential velocity of particle
R = radius of circular path of particle
g = acceleration due to gravity

Combining equations (2) and (6) the terminal velocity in a centrifugal field, for particles in the Stokes' law range is:

$$(7)\ V_e = \frac{V_t^2\ D^2\ (d_p - d_f)}{18\ Rn}$$

In a given mechanical collector, V_t at any point is proportional to the volume of gas passing through the collector, and R at any point is a constant. Therefore, for a given collector, equation (7) becomes:

$$(8)\ V_e = \frac{K\ Q^2\ D^2\ (d_p - d_f)}{n}$$

Where V_e = equivalent terminal velocity in collector
K = a constant for this collector
Q = capacity, or volume of gas passing through the collector in CFM.

Let us assume that the same dust particles pass through this collector with different fluids of viscosities n_1 and n_2 and densities d_1 and d_2. Substituting in (8) we obtain:

$$\text{For fluid \#1}\ V_{e1} = \frac{K\ Q_1^2\ D^2\ (d_p - d_{f1})}{n_1}$$

$$\text{For fluid \#2}\ V_{e2} = \frac{K\ Q_2^2\ D^2\ (d_p - d_{f2})}{n_2}$$

Now assume that the collector efficiency is the same in both cases, that is $V_{e1} = V_{e2}$. Then:

$$\frac{K\ Q_1^2\ D^2\ (d_p - d_{f1})}{n_1} = \frac{K\ Q_2^2\ D^2\ (d_p - d_{f2})}{n_2}$$

Solving for Q_1 we obtain:

$$(9)\ Q_1 = Q_2 \sqrt{\frac{n_1\ (d_p - d_{f2})}{n_2\ (d_p - d_{f1})}}$$

But, d_f for air or flue gas is insignificantly small compared with d_p. For all practical purposes, equation (9) may be simplified to:

$$(10)\ Q_1 = Q_2 \sqrt{\frac{n_1}{n_2}}$$

From equation (10) the following rule for viscosity correction can be formulated:

For particles in the Stokes' law range, a change in fluid viscosity is equivalent to a change in collector capacity proportional to the square root of the viscosity ratio.

For the collector under consideration, this correction is insignificant for flue gas temperatures below 400°F. For higher temperatures, the temperature correction factors charted on Fig. 2 should be applied. To use this chart:

Multiply % of rated capacity by temperature factor, from upper curve, Fig. 2. This gives "Equivalent % capacity."

Read "Particle Diameter Factor" corresponding to "Equivalent % Capacity" on lower curve, Fig. 2.

Multiply D_e by "Particle Diameter Factor." Product is corrected equivalent diameter D_c.

Read fractional efficiency from Fig. 1 at D_c.

A typical example of the application of this data is presented in Table II.

A point not covered in the above discussion is the dust loading correction. The efficiency of an Aerodyne is a function of dust loading, but the effect is insignificant over the range of loadings generally encountered in air

TABLE II. TYPICAL EXAMPLE, AERODYNE EFFICIENCY CALCULATIONS

Specified conditions:
65,000 CFM of flue gas at 650°F.
Specific gravity of dust 2.3
Dust analysis per first two columns of

Collector Selected:
Size cones 19 – 3/4
No. of cones 10
Rated capacity 73,000 CFM (Table 1)
% Rated Capacity 89
Temperature Factor 0.90 (Fig. 2)
Equivalent % Capacity 80 (% capacity × Temp. Factor)
Particle Diameter Factor 0.974 (Fig. 2)

Size Range Microns D_t	% In Range	Mean D_t (2.3 sp.g.)	D_e (1.0 sp.g.)	D_c (D_ex.974)	Fractional Eff. % (Fig. 1) (@D_c)	% Recovered (Fract. Eff. x% in Range)
0 – 5	7	2.5	3.8	3.7	17	1.2
5 – 10	21	7.5	11.4	11.1	63	13.2
10 – 20	26	15.0	22.8	22.2	93	24.2
20 – 30	16	25.0	37.9	36.9	99	15.8
+ 30	30	+30.0	45.5	44.3	100	30.0

Overall efficiency 84.4%

pollution control. Therefore a detailed discussion of this phenomenon is outside the scope of this paper.

A better understanding of the many variables which affect dust collector performance would be of great value to everyone dealing with air pollution control problems. It is hoped that this paper may offer some slight contribution to this end.

Other References

Montross, Charles F. "Entrainment Separation". Chemical Engineering, Vol. 60, No. 10, pp 213-236, 1953.

Kaiser, Elmer R. "Problems in the Control of Dust from Coal-Fired Boiler Furnaces", Bituminous Coal Research, Inc.

"Symposium on New Methods for Particle Size Determination in the Subsieve Range", Special Technical Publication No. 51, American Society for Testing Materials.

(Continued from page 4)

Thermal Precipitation

The high efficiency, close to 100 per cent for all particles ranging in size down to the limits of resolution of the electron microscope, would indicate that this is an excellent instrument with which to measure the efficiencies of all other aerosol sampling and collecting devices.

The ease of operation makes this an excellent sampler for air pollution studies. The limitations of thermal precipitation as a tool for the examination of airborne particles are: the low sampling rate, the precision necessary to construct the device and the low thermal efficiency.

The advice and guidance of J. M. DallaValle of the School of Chemical Engineering and T. W. Kethley of the Engineering Experiment Station in this work is gratefully acknowledged. The investigations leading to the designing of the sampler described herein were supported in part by a grant-in-aid from the National Institutes of Health.

(Continued from page 34)

Factors in Dust Collector Design

A lubrication schedule for all moving parts requiring oil or grease should be adhered to, and, of course, all worn or defective parts must be promptly replaced.

All electric precipitators are sold with an overall collection efficiency guaranteed for certain operating conditions. Most of these precipitators are tested by the manufacturer shortly after installation, and adjusted to attain the guaranteed efficiency. However, unless the purchaser maintains and operates the precipitator properly, it may go through a large portion of its economic life collecting dust at a reduced efficiency.

How many tons of fly ash and other contaminants are needlessly discharged into our atmosphere through negligent operation of good dust collection equipment? No one knows, but it is a figure that can, and certainly should be, reduced.

Filtration of Hot Gases

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Nearly every air pollution control ordinance now existing has its origin in so-called smoke control regulations which were designed to limit the density or opacity of smoke discharged from coal burning equipment. The smoke regulation concept has carried over into present-day air pollution ordinances, in that some restrictions on the opacity of industrial stack gases are in effect wherever air pollution laws have been enacted. Thus, the visual appearance of effluent stack gases forms the basis for a rough, qualitative appraisal of the amount of solid particles they contain. In some areas, attempts have been made to reduce allowable stack emissions to a quantitative basis and ordinances have been enacted which include restrictions on either the concentration or the mass rate of emission of contaminants which may be discharged to atmosphere in industrial waste gases.

As experience is gained with existing restrictions, it is reasonable to expect that changes and modifications will be made which will tend to further reduce allowable stack emissions.

At present, there are no legal requirements that effluent stack gases be free from visible contaminants, and the possibility of such restrictions in the foreseeable future is remote. However, from the standpoint of public relations, a stack discharge containing sufficient visible contaminants to be conspicuous should be avoided wherever possible.

Aside from fly ash and carbonaceous smoke from coal burning equipment, dust and fume from furnace operations in the ferrous and non-ferrous metals industries present the most perplexing problems in air pollution control. The design of cleaning equipment for furnace gases is complicated by high temperatures, fluctuations in gas volume, temperature, and dust burden, and the predominance of extremely fine particles which, by reason of their high degree of light refraction, are conspicuous to the eye even when present in very small concentrations in the effluent gas.

Particularly in the case of gases from open hearth and electric steel furnaces, a reduction in either the concentration or mass rate of emission of extremely fine solid particles sufficient to meet the requirements of most air pollution control ordinances has only a minor effect on the appearance of the stack discharge. Vajda(1) has estimated that the solids content of gas from open hearth steel furnaces must be reduced to 0.05 grains/cu. ft. or below if visible discharge is to be avoided. Zang(2) has stated that effluent ventilation air from electric furnaces which contains 0.15-.18 grains solids/cu. ft. is objectionable in appearance even though about 74 percent of the total fume has been removed by scrubbers prior to discharge.

If it is assumed that a solids concentration in effluent gases greater than 0.05 grains/cu. ft. produces a visible discharge, then equipment installed for gas cleaning must, in order to prevent the venting to atmosphere of visible solids, have the ability to consistently remove the following percentages by weight of total gasborne solids:

Initial Solids Conc. Grains/Cu. Ft.	*Required Efficiency Percent by Weight*
0.25	80.0
0.5	90.0
1.0	95.0
2.0	97.5
5.0	99.0

Of the gas cleaning equipment presently operating on various types of metal melting furnaces, only cloth filters have consistently produced effluent discharges free from visible solids. Because of this, baghouses are becoming more widely accepted for air pollution control.

In the non-ferrous smelting industry, particularly in those plants smelting lead and zinc ores, baghouses have been used for years for the recovery of values. Wool was the filter fabric employed. This material could withstand temperatures up to 215°-220°F. and had satisfactory resistance to low concentrations of sulfur dioxide and sulfur trioxide. The cost of replacing these wool filter bags was justified by the fact that the material collected had a definite value; in fact, without the recovery of the values in the suspended dust and fume in smelter gases, operation of many smelters would have been economically impossible.

The "old fashioned" smelter baghouses were designed to operate at very low gas-to-cloth ratios (CFM per square foot of cloth) ranging from 0.5 to 1 up to 1.0 to 1. Naturally, the size of these structures was such that considerable ground space was taken up, and the handling of the collected dust and fume posed some difficulties. Before cloth filtration of hot gases for the elimination of air pollution could be practiced on any reasonable scale, it was necessary to adapt the modern, compact baghouse to high temperature service and to develop filter fabrics which would give longer service at higher temperatures than

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[1] Vajda, S., and Dreher, G. M., "Open-Hearth Dust Control", A. P. and S.P.A., June 9-12, 1952.

[2] Zang, V. E., Remarks at AIME Electric Furnace Steel Conference, Pittsburgh, Pa., 1952.

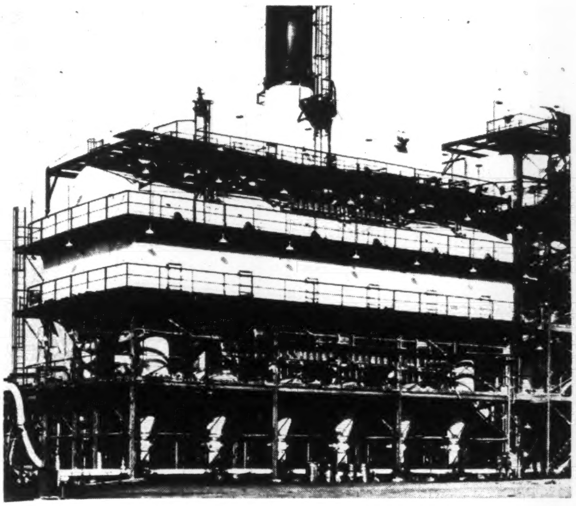

Fig. 1. Special 12-compartment carbon black collector with orlon bags filtering production gas following electrostatic precipitator and cyclones. Phillips Chemical Co., Borger, Texas.

the wool fabrics originally employed in the smelting industry.

Beginning in 1946, experimental field work was conducted with a number of newer synthetic fabrics. Temperature limits and operating characteristics were determined under field conditions. It was found that filter bags fabricated from DuPont's Orlon acrylic fiber could be economically operated at a maximum temperature of 275°F. (55° above the maximum limit for wool filter bags) in the presence of appreciable concentrations of acid gases and water vapor. However, in bringing this research to a successful conclusion, it was necessary to develop weaves of fabric which would have optimum permeability and dust retention properties and to perfect a technique for heat setting the fabric prior to sewing it into bags in order to eliminate shrinkage under operating conditions.

Orlon fabrics for hot gas filtration were first brought into commercial use in the carbon black producing industry, and, as a result of early experimental use, more than 40 large baghouses of special design, similar to that illustrated in Figure 1, have been installed. Most of these units are tertiary collectors backing up electrostatic precipitators and cyclones. Spray coolers are used in reducing the gas temperature from 2000°F. down to the filtration temperature.

Early experimental work in filtration of hot gases in Los Angeles County was based on the use of open type baghouses employing relatively large diameter filter bags made from Fiberglas fabric which had undergone a variety of treatments. Shaking the bags at intervals is necessary to remove the accumulated deposit of dust and fume from the filtering surfaces in order to restore original low operating back pressure, and a successful filter fabric must be able to withstand the degree of flexing required by the shaking process. Early experience with the untreated Fiberglas fabrics indicated that these filter media were entirely unsuccessful from the standpoint of resistance to mechanical injury during handling and shaking. In spite of this drawback, the use of Fiberglas had an obvious advantage, in that it could withstand operating temperatures in the neighborhood of 400° to 450°F. Today, all Fiberglas filter fabrics used in hot gas cleaning have been treated to remove lubricants used in weaving and impregnated with a lubricant such as a silicone resin in order to eliminate breakage of individual glass fibers during flexing of the fabric. It is now possible to obtain an economically feasible bag life using Fiberglas filter fabrics with carefully controlled mechanical shaking of the bags. It is expected that progress in the development of Fiberglas filter fabrics will continue.

Other synthetic fabrics have been evaluated with respect to their usefulness in hot gas filtration. These include Nylon, Vinyon, Dynel, Dacron, etc. In no case were these fabrics found to be capable of withstanding continuous operation in the temperature ranges for which Orlon and Fiberglas fabrics are suitable. However, some of these fabrics possess resistance to certain chemicals which has justified their use in special cases. For example, Nylon possesses superior resistance to alkaline materials and is often used in gas filtration at a maximum temperature of 225°F. Vinyon possesses satisfactory resistance to certain chlorides and, to a lesser extent, fluorides; however, its maximum operating temperature is 200°F., and this limit has sharply reduced its general applicability. Teflon filter fabric is now being produced by DuPont on a pilot scale for field evaluation in hot gas cleaning. While its chemical properties and heat resistance are of considerable interest, its commercial use may become a matter of comparative economics.

Gas Cooling

The application of cloth filtration to the cleaning of furnace gases requires in most cases that the gases be cooled in order to protect the filter fabric and to insure economical fabric life. The following three cooling methods are employed singly or in various combinations:

1. Radiation and convection (requires a relatively large investment in U-tube coolers, heat exchangers, etc.)
2. Tempering air (results in relatively large filtration volumes with a resultant increase in the size of the gas cleaning equipment.)
3. Spray cooling (the most economical with respect to capital investment, but requires careful control of cooling water sprays in order to keep the dew point at a minimum.)

Cooling by radiation and convection ordinarily employs U-tube coolers (familiar sights in many non-ferrous smelters) or heat exchangers such as waste heat boilers or forced draft tubular condensers. U-tube coolers consume a relatively large amount of ground space and require considerable lengths of heavy steel duct work from which heat is radiated at a low rate. U-tube coolers lack flexibility with respect to final temperature adjustment, and their use often results in inadequate cooling in hot weather and overcooling in the winter time. Waste heat boilers are economically feasible wherever there is need for steam or electric power. They require a large capital investment, but because of the financial return in the form of steam or power, they usually pay for themselves in a reasonable time. Obviously, a furnace operation which is intermittent in nature cannot support waste heat boilers. Tubular heat exchangers, utilizing outside air supplied under forced draft around the outside of the hot gas carrying tubes, have been successfully employed. Because of the use of forced draft for secondary cooling air, tubular heat exchangers are relatively economical as far as space requirements are concerned and offer more flexibility in final temperature adjustment than do either U-tube condensers or waste heat boilers. The use of any of the above cooling devices is more attractive if they are supplemented by either spray cooling or the admission of tempering air for final temperature adjustment.

Cooling gases already high in water vapor content is frequently accomplished by the admission of outdoor air through full modulating bleed-in dampers. Precise regulation of filtration temperature is readily accomplished by this method, but since the outside air admitted for cooling purposes must also pass through the filter bags, it is obvious that the size of the filter itself must be considerably larger for tempering air cooling than for the other two methods listed above. In some cases where gas being filtered contains explosive gases, the admission of oxygen is objectionable for reasons of safety.

Since a gas cleaning system installed for air pollution abatement is usually a non-productive expenditure, the equipment cost must be kept at a minimum. For this reason, spray cooling of hot gases is the most attractive of the available methods since it is reasonable in first cost, easily maintained, and results in only a nominal increase in the volume of gas to be filtered.

To illustrate the above differences in cooling methods, a hypothetical problem has been worked out with the results shown below. In all cases, it is assumed that 30,000 CFM air at 600°F. containing 0.01 lb. water vapor per lb. dry air is to be cooled for filtration. An 80°F. ambient temperature is assumed; tempering air is taken at 80°F. with 0.01 lb. moisture per lb. dry air, and water is assumed to be available at 70°F. Extraneous heat losses are not taken into account.

	Cooling Method		
	U-tube	Temp. Air	Water
Wgt. dry air, lb./min.	1,096.1	1,096.1	1,096.1
Wgt. water vapor, lb./min.	10.9	10.9	10.9
Wgt. mix, lb./min.	1,107.0	1,107.0	1,107.0
Ave. radiation loss, Btu/sq. ft./hr./°F.	1.0		
Btu/min. to be removed	89,443	89,443	89,443
Req. U-tube surface, sq. ft.	15,248		
Length, 42" dia. pipe, ft.	1,387		
Wgt. 10 ga. U-tube, less hoppers, lb.	85,770		
Wgt. temp. air, lb./min.		1,547.6	
Wgt. cooling water, lb./min.			90.30
Vol. temp. air @ 275°F., CFM		28,838	
Vol. cooling water vapor @ 275°F., CFM			2,692
Vol. orig. mix @ 275°F., CFM	20,629	20,629	20,629
Vol. to be filtered @ 275°F., CFM	20,629	49,467	23,322
Percent filter area required	100	240	113
Dew point	58°F.	58°F.	125°F.

This example illustrates the economic advantage in water spray cooling. From the operating viewpoint, the filtration temperature is a safe 155°F. above dew point, and with proper spray cooler design, no difficulties would be encountered.

An 8′-0″ diameter cooling tower suitable for the above example should provide 31′-0″ unobstructed travel of spray below the nozzle to preheat and completely evaporate all water droplets 200 microns and smaller in diameter. One commercial spray nozzle frequently used atomizes 96 percent of the water into 200 microns and smaller droplets at 475 psig. water pressure, leaving 4 percent by volume incompletely evaporated. The water runoff from the tower would be a small fraction of the 4 percent incompletely evaporated and can be eliminated by basing the cooler design on the maximum droplet size encountered. The amount of water added to hot gases for cooling in bag filter installations is less than that frequently found necessary for gas conditioning in electrostatic precipitation of furnace fume.

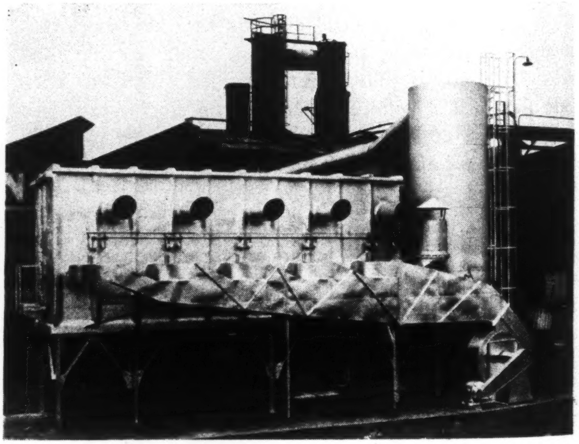

Fig. 2. Continuous automatic cloth filter cleaning cupola gases, Lincoln Foundry, Los Angeles.

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Examples of Hot Gas Filtration

Grey Iron Foundry Cupolas: Although there are many successful installations of cloth filters cleaning gases from grey iron foundry cupolas in Los Angeles County employing either Orlon filter bags or Fiberglas filter bags, reliable quantitative data have been published in connection with only one of these installations. Details of the cupola fume collection system installed at the Lincoln Foundry (Fig. 2) in Los Angeles appear in the original article (3) and they are summarized in Tables 1, 2; and 3 as a matter of convenience. After more than two years of successful operation of this equipment, the following statements are in order:

1. In designing the system, there was never any doubt as to the eventual performance of the installation.
2. No expensive and time-consuming adjustments were required after installation in order to obtain performance equal to that anticipated during the design stage. Approval by the air pollution control authorities was granted a few days after the equipment was first placed in operation.
3. The effluent cleaned gas is consistently free from visible solids.
4. The initial set of Orlon filter bags is still in operation after two years, with no replacements. The condition of these filter bags is excellent.

Table I—COMPARISON OF DATA BEFORE AND AFTER INSTALLATION

	Without Corrective Equipment 1-10-51	With Equipment 10-8-52
I. D. of cupola at melting zone—inches	54	54
Average volume of stack gases—cfm	51,000	29,000
Average temperature of stack gases—degrees F.	1,046	1,580
Volume of stack gases calc. to 60°F.—scfm	17,700	7,400
Maximum temperature of gas during burn down—degrees F.	1,400	1,790
Height of cupola stack above charge opening—feet	13	23
Dust up cupola stack—grains per scf during charging period	1.15	1.42
Dust loss up cupola stack during charging period—pounds per hour	174	90.3
Area charge opening—square feet	47	27.8
Tuyere air scfm—60°F.	4,600	4,200
Operating cycle—minutes	320	279
Material charged (2000 lbs. per charge)		
Bed coke—pounds	2,900	3,000
Coke—pounds	10,520	10,560
Metal—pounds	67,390	56,000
Limestone—pounds	2,025	2,480
Briquets—pounds	1,065	1,440
TOTAL	83,900	73,480
Process weight per hour—pounds	15,730	15,800
Dust loss to atmosphere allowed by law	13.58	13.62

TABLE 2—GAS VOLUMES AND COOLING SYSTEM PERFORMANCE

	Actual Measurements taken 10-8-52
Volume of stack gases calc. to 60°F.	7,400
Tuyere air—scfm—60°F.	4,200
Average stack temperature—degrees F.	1,600
Maximum stack temperature—degrees F.	1,790
Average water consumption in quencher—gpm	28.9
Run off quencher—gpm	5.4
Average water converted to steam—quencher—gpm	23.5
Average water consumption in secondary cooler—gpm	5.01
Run off secondary cooler—gpm	2.11
Average water converted to steam—secondary cooler	2.9
Water pressure at both coolers—psig	120
Temperature exit of quencher—degrees F.	425
Temperature, inlet to secondary cooler degrees F.	415
Temperature, exit of secondary cooler—degrees F.	268
Volume entering baghouse@ 275°F.—cfm	16,990

TABLE 3—PERFORMANCE OF FUME COLLECTION SYSTEM

	Measured 10-8-52
Gas volume entering filter @ 275° F.—cfm	16,990
Square feet of cloth	
with 5 compartments filtering	7,320
with 4 compartments filtering	5,856
Gas-to-cloth ratio	
with 5 compartments filtering	2.3
with 4 compartments filtering	2.9
Shaking cycle, minutes between shaking periods, each compartment	15
Shaking duration, minute per cycle	1
Gas temperature, degrees F.	268
Calculated dew point, degrees F.	167
Pressure loss through bags, inches water	
with 5 compartments filtering	5.9
with 4 compartments filtering	6.7
Exhauster motor H.P. rating	40
Average weight dust caught, lbs. per hour	
in quencher	31.2
in secondary cooler	6.4
in dust collector	47.3
Total	84.9
Average dust loss in collector exhaust, pounds per hour (thimble test)	0

(No increase in weight in one hour sample)

The unit operates as a pressure unit on the positive side of the fan. The filtered air discharges directly through the dust collector housing to atmosphere and is completely free of visible solids. The following is a tabular summary of operating conditions:

Gas volume, CFM	21,000
Gas temperature, max.	161°F.
Normal pressure drop across filter, in W.G.	3.0"
Approx. wt. fume collected, lbs./hr.	190
Ave. grains/cu. ft., inlet	1.3
Length of heat, minutes	70
Operating hours/week	54
Type filter bags	B-23 Orlon
Type shaker	Mechanical
Visible solids in effluent	None

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[3] I'Anson, J. E., Harsell, T. L., Jr., and Pring, R. T., *American Foundryman,* Jan. 1953.

Fig. 3. Canopy-type swivel hood in position over 5-ton electric furnace at Midwestern Steel Foundry.

5. Performance is consistently satisfactory, there being no variation in collection efficiency with changes in the nature of the gas or of the entrained solids.

Electric Furnaces: A recent publication by O. E. Erickson[4] presents a brief and to-the-point summary of experience in the Los Angeles area with various types of equipment for cleaning ventilation air from electric furnaces. The author concludes that the tubular type bag filter using Orlon bags has been the most successful for cleaning electric furnace gases.

Because of a relatively high infiltration rate of room air through either the roof top furnace hood or the overhead canopy type, filtration of the fume laden gases through either Orlon or Fiberglas filter bags can be carried out without the necessity of cooling the gas prior to filtration. An electric furnace ventilating system employing filtration is, therefore, a relatively straightforward and simple one, involving few problems other than proper hooding and the selection of the most suitable filter medium. Panel or screen type dust arresters were tried but were unsuccessful because of the difficulty of removing the collected fume from the surface of the filter panels with the shaking action employed by this type of filter.

In a mid-west plant producing steel castings, there are two five-ton electric furnace shells mounted on a turntable and using a single set of electrodes alternately so that when one furnace is being poured, the other is on "melt down". Because of the peculiarities of the operation, the usual roof top type of hood could not be used; instead, a modified overhead canopy designed by a consultant is used (Fig.3) which pivots out of the way when electrodes are slipped. From this overhead type of hood, the accumulated gases are passed through an exhauster and into a three compartment continuous automatic tubular-type dust collector (Fig. 4) employing Orlon bags.

Open Hearth Steel Furnace: For several years, pilot scale testing has been conducted by major steel companies for the purpose of evaluating available equipment to clean open hearth furnace stack gases. Until recently, the equipment tested has been limited to scrubbers, traveling bed filters, electrostatic precipitators, and combinations of sonic agglomerators with secondary collection devices. Recently, however, a very comprehensive pilot scale test of a tubular baghouse has been completed. The results of this test indicate that cloth filtration of open hearth furnace gases is entirely feasible. Analysis of estimates and bids covering equipment for ten open hearth furnaces revealed that the system employing cloth filtration would cost approximately 78% of a similar system employing electrostatic precipitation, both estimates being on an installed basis.

There are certain phases of open hearth furnace steel operation which are unique, insofar as they affect the design of a gas cleaning system. The gas volume, gas temperature, and concentration of dust and fume vary sharply according to the particular phase of the heat.

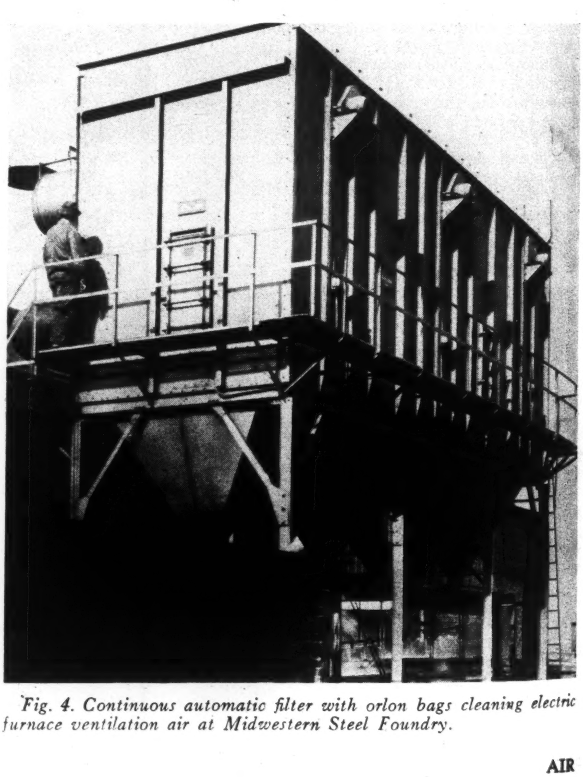

Fig. 4. Continuous automatic filter with orlon bags cleaning electric furnace ventilation air at Midwestern Steel Foundry.

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[4] Erickson, O .E., "Electric Steel Foundries Control Dust Emissions in Los Angeles Area", AIME Electric Furnace Steel Conference, Cincinnati, Dec. 4, 1953.

Adequate control of the emissions from open hearth furnaces requires a very careful study of these variables, extending over a considerable period of time. In a plant operating several open hearth furnaces, each with its own stack, it is possible, but not economical, to install separate collectors for each furnace. In the case of cloth filters, it is desirable to design them for the maximum anticipated gas volume and temperature, resulting in excessively large collectors and accessories. In the case of less positive devices, such as electrostatic precipitators, it is conventional to design the collectors for average gas volumes, in which case the precipitators are allowed to puff dust through to atmosphere during overload periods. It is far preferable to install a central system in which gases from all furnaces are combined in order to minimize the effect of variations in any given furnace at any particular time. By this means, fluctuations in all three of the above variables can be minimized and the size of the necessary equipment be kept at a minimum.

In the pilot scale test mentioned above, a representative portion of furnace gas was withdrawn from the breeching leading to the stack and downstream from the waste heat boiler and induced draft fan. The gas was cooled in a spray tower and a representative portion of the cooled gas passed through a bag filter containing B-21 Orlon bags. The validity of both sample splits of the gas was verified by simultaneous thimble samples. Typical test results covering one entire heat are summarized in the following:

	Total Dust Conc., Grains/SCF		Collection Efficiency
	Inlet	Outlet	Percent
Lime boil	1.26	.007	99.44
Working	.66	.002	99.70
Working through tap	.64	.002	99.69
Charging and melt down	.11	0	<100
Hot metal add. and ore boil	.33	0	<100
Lime boil	.39	.003	99.23
Lime boil	.43	0	<100
Pressure drop across bags	1.1 — 1.6″ W.G.		
Temp. before cooler	453°F.		
Temp. after cooler	286°F.		
Cooling water rate	37.5 g.p.h.		
Cooler runoff	None		
Visible solids in effluent gas	None		

This pilot test was the most comprehensive evaluation of experimental baghouse performance ever made, to the writer's knowledge. It clearly indicates that cloth filtration of open hearth furnace gases merits serious consideration as a positive means of completely eliminating visible stack effluents.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the assistance of Messrs. G. W. Roper, F. A. Lindahl, and W. T. Morecraft, American Wheelabrator & Equipment Corp., in assembling and checking data, and of Mrs. Dorothy D. Lott in the preparation of the manuscript.

(Continued from page 19)

Coal Segregation

namely, air and moisture. Air segregation is usually caused by poor design on the air ducts or of the plenum chamber. Many cases of poor fires on stokers are blamed on air segregation, but in most of these cases, careful analysis has proved that coal or moisture segregation were the real sources of trouble.

On chain-grate stokers, moisture segregation often produces a fire similar to that produced by coal segregation with the exception that coal segregation always produces a definite pattern, whereas, moisture segregation usually produces a variable pattern. Most cases of moisture segregation are the result of irregular tempering of the coal by steam in the stoker hopper. From our observations, it is recommended that, if coal is to be tempered by steam, it should be done in a downspout ahead of the distributor, or the coal should be tempered by water as it is introduced into the bunker.

Conclusion

In order to produce a good fire with the minimum of smoke, it is necessary that the equipment of the plant be such that the coal will not be segregated as it is fed to the stoker hopper. This requires properly designed coal handling and bunker to stoker equipment.

The elimination of coal segregation within the boiler plant should be done when the plant is still in the design stage. The illustrations given here can be used as a gage to indicate where segregation will occur. Well considered design will isure that the plant, when built, will give proper operating results. It is just as important to check proposed coal handling equipment from a coal segregation point of view as it is to check the drawings for dimensional accuracy. In an existing plant, coal segregation may be eliminated either by proper operation of equipment as installed or by revising that equipment to accomplish the designed results.

Although coal segregation is only one of the many causes of smoke in stoker fired plants, its elimination can be justified in the saving of fuel, in increased capacity of the boiler unit, and in the reduction of maintenance costs. Therefore, coal segregation elimination will not only make the boiler plant a better neighbor, but it will also make it a more profitable unit.

Management's Responsibility to the Community

Richard K. Mellon*
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Let us review the change that is taking place in the businessman's conception of his place in the community. In discussing this change I do not distinguish in my own thinking between the businessman and the corporation of which he is one of the managers, because the corporation is the legal entity in which this sphere of his activities centers.

It seems to me that a close parallel may be drawn from a historical review of the ethical progress and development of the *individual* and of the *corporation.* One can say, I think, that the individual has proceeded from an insistence upon personal rights to an understanding that duties were inherent in those rights, and then to the intelligent performance of those duties. And so the corporation is proceeding from the stage of living within legal rights and powers to a new stage of recognition of corporate responsibilities and duties to society from which those rights are received.

At one time this concept of duty to society was certainly at a low level. Business and the businessman could and did live pretty much to themselves. The businessman's responsibility seemed to be limited to himself and his associates. His sole interest was to make money, and about the only audience he addressed was his own stockholders.

But with our industrial development came a gradual enlargement of this narrow field of responsibility to embrace the wider areas of duties to employees and to customers. Today we see a widening of this sphere of responsibility from these three groups to a fourth all-pervasive group—*the duty to the general public.* Much of this forward-looking concept reflects a change in the type of men who are, or are about to become, top managers of today's industry. Increasingly are future executives being trained in such excellent schools of business administration as Wharton. To the responsibility for production, top industrial leadership today is raising its sights to include a feeling of responsibility toward the social and political problems of our modern industrialized society. If this development is still not universal in industry, at least the trend toward recognition of these enlarged responsibilities is clear and definite. Thus, management today, in contrast with its early history, represents more than single interest in ownership; management today is attempting to maintain a proper sense of balance in an expanded, inter-related group—the stockholders, employees, customers, *plus* the general public.

To refer to "public interest" is simply a more modern way of saying that the businessman (and the corporation which in the eyes of the law is a "legal person") has an unavoidable duty toward the *entire* environment in which he lives, moves, and has his being.

Let us examine three areas of the environment in which we businessmen work today.

One— The area of government and public policy.
Two— The area which embraces the physical characteristics of the community.
Three—The area of educational, health, cultural, and social needs of the community—*general welfare*—to use an all-inclusive phrase.

I should like to discuss with you the area of government and public policy. As I see it, government is the administrative regulation of men, or at least certain of the affairs of men. Fundamentally, the political problem would appear a problem of human character. Many, many centuries ago a great statesman said, "Governments vary as the dispositions of men vary. States are made not out of rocks or trees, but from the dispositions of their citizens which turn the scale and draw everything in their own direction."

We businessmen must participate in the formation of public policy even though the particular issues may not have an immediate influence upon our individual businesses. This necessitates unselfish leadership and personal participation. However important the daily conduct of our business is to all of us, however demanding upon our time and energy, it is clear that we cannot isolate ourselves from the universal public service demands and the social problems which surround us. We cannot get away from the obvious fact that the very basis of our industrial society rests upon the environment in which we live—a society of free men in which the individual has the right to progress according to his ability. After all, *performing is better than defending* when it comes to selling "free enterprise." The businessman must carry his full share of promoting free enterprise, the only climate in which our high state of industrialism can exist, based as it is on individual initiative and the pioneering spirit.

Let us, for example, consider briefly the need for greater interest on the part of the businessman in one public field —that of public schools. Our public school system is a dynamic organization of one million school teachers teaching twenty-five million youngsters graduating each year one million high schools pupils, of whom about five hundred thousand enter college. From these schools come our future workers, professional men, managers and public leaders. That is why it is essential that businessmen in their respective communities should assume an active interest in public education. Our public schools provide the environment in which American youth are trained for their individual share of responsibility in our democracy. Public schools *must* have a good climate in which to develop good citizenship.

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*From the address delivered by Mr. Mellon upon the occasion of receiving the Fourth Annual Gold Medal of Merit Award of the Wharton School of Finance and Commerce Alumni Society, University of Pennsylvania at Philadelphia, Pa., November 16, 1953.

With countless others, I have been a participant in a community development in which many active businessmen shared. You know something of what some have called the "Renaissance of Pittsburgh." Among other things, it has turned the streets of Pittsburgh from darkness into light and lifted the soot from our window sills. We had our smoke, at least it was far more fabled with us than with some other cities; we had from nature not the most desirable terrain for the layout of a modern city; we had as a consequence a traffic problem almost incomparable with that faced by cities of similar size. All these and other conditions made the heart of our city something less than satisfactory. Perhaps we may summarize what happened in our city by pointing out that many Pittsburgh citizens acting collectively, and regardless of their political affiliations, raised the important issues and found the technicians who resolved the answers. In the answers lay a large part of the future economic health of our community.

When you come to Pittsburgh again you will see the face of the Golden Triangle changed materially; you will see still under way many projects both in and around that central area; and there are many more to come. These are the superficial aspects.

Underlying these projects, giving them economic meaning, is the reconstruction which has reversed the economic and industrial trend of the entire Pittsburgh area. I submit that here is a good example of businessmen and other public-spirited citizens working together to achieve a goal not so long ago considered visionary.

Now let us turn briefly to the problem of financial assistance to community causes — community welfare, higher education, social services—yes, and even cultural activities. Historically these have been considered areas for the leadership (and the wherewithal) of the enlightened and generous private citizen. But with high income, estate and inheritance taxes, individual donors cannot be expected to provide financial support to the extent that has been possible in the past. Accordingly, the corporation is bid to step into the breach.

Now then, can it be done? Can a company donate money to a school without getting a direct return from the donation? In the not so distant past the legal concept was what our legal advisers termed *ultra vires:* that is, beyond the power of the board of directors, as expressed in the company's charter, to make gifts for causes or purposes not *directly* connected with the administration of the business. In other words, it was not for the board of directors to decide how the stockholders should dispose of their money. But public opinion and a re-examination of this legalistic approach are breaking down this barrier to giving. Thus, a basic change in point of view has occurred in the past few years.

For example, more than half of our states (including the Commonwealth of Pennsylvania) have enabling laws for charitable contributions by corporations, and more than half of those laws have been passed since 1945. This, in my opinion, is encouraging. Also, most of you are familiar with the provisions of our Federal income tax laws, allowing specified tax exemptions to corporations for philanthropic gifts. The most recent court case I know was in the New Jersey Superior Court earlier this year in which it was ruled that an unrestricted gift by a corporation to a well-known university, to be used "toward the maintenance of the university," was legal. The New Jersey Supreme Court affirmed the lower court and the Supreme Court of the United States subsequently refused to review the case, and so the decision stands. In the words of the New Jersey statute, companies are authorized to make charitable contributions—"conducive to the betterment of social and economic conditions."

The fact that during 1953 corporation gifts to various worthy purposes are estimated to exceed three hundred million dollars as against thirty million dollars in 1936 is evidence of the trend of corporation giving which has taken place in the past few years.

It is instructive here to examine the present-day stockholder's attitude toward corporate giving. A public opinion survey earlier this year showed that stockholders believe management is justified in making contributions from company funds for:

Community chests	75%
Colleges and universities	74%
Hospitals and health organizations	67%
Social welfare agencies	49%
Churches and religion	33%

Much of our industrial progress is due to advancements in science. The basis of this progress is technical training, and an important beneficiary of such training is American business. The cost of this education is so great today that present low endowment incomes, gifts from individuals and tuition payments by students do not cover the costs. Education or any other free enterprise, as you well know, cannot long continue at a loss. And furthermore, is it not reasonable, and, in fact, essential that corporations pay something toward training such students, many of whom they will later absorb? That some corporations are already meeting these needs with financial help is merely a good example of enlightened self-interest.

Cannot a similar case be made out for the strictly liberal arts colleges? They, too, are preparing an important proportion of our young men and women for citizenship and the eventual management of enterprise. Here again low endowment incomes and high costs have produced a serious problem. Certainly freedom of education and freedom of enterprise are essential ingredients of the kind of life we want continued. One of our great industrialists, Irving S. Olds, formerly Chairman of the United States Steel Corporation, has said, "Corporations should help underwrite the pure business of developing and improving the human mind."

It is also clear that the social welfare needs of the community affect the spiritual as well as the physical health of our environment. Community chests, adequate hospital facilities, for example, represent some of the important factors for good in a modern community. Do not gifts to community enterprises help to preserve our form of society which makes possible the continuation of business motivated by responsibility, initiative and leadership?

It was Abraham Lincoln, I believe, who said, "A man cannot be truly happy unless he is doing something for somebody else." Participation by business leadership in community activities provides such a vehicle for basic happiness. After all, we must consider people and their individual happiness. Part of that happiness is supplied by the environment under which they live and work. People live in the same communities in which corporations do business, and they and their neighbors work for them. They expect business to be a good neighbor, and a good citizen. And good neighbors collectively make a good community in which to live. A livable community must have opportunities for leisure and culture after the workday is done. That is why some cities use tax money to help support various worth-while community activities, and why, indeed, some forward-looking corporations provide financial help for similar objectives.

This newer tendency of modern corporation management to develop a good social sense is complementing the former emphasis on production problems. As evidence of this enlightened attitude, some corporations have in the past few years established charitable foundations to implement the conception of broader responsibilities for financial support to community activities, higher education and social-service projects. This is a good sign—and worthy recognition of the "good neighbor" policy.

Like the world we live in, business is changing and, I believe, for the better. It has not been anesthetized by those persons who believed our economy was mature (you will recall how the phrase "matured economy" crept into our vocabulary in the early 30's). In spite of the fact that the conviction seemed to exist in many quarters that our economy was mature, that the frontiers had been passed, science, technology *and* business created new frontiers. There *was* a time when business and businessmen lived pretty much to themselves. But just as it is impossible today to keep technology and the sciences in isolated compartments, so is it impossible to separate business from the social and personal tides of our economy.

Many organizations have established special departments or other instrumentalities to enter into corporate giving with minimum waste and maximum effectiveness. Others, as I have mentioned, have established charitable trusts. The problem is not whether; the problem is how. It is sometimes more difficult for a corporation to give money away wisely than, perhaps, to make it.

The financial implementation of corporate responsibility to community well-being is by no means a universal movement, nor a common and everyday policy in the business world. But here is represented the considered judgment of the most enlightened minds in business and the spirit in which many leaders among corporations are approaching the subject.

Managements have come to realize that they now are responsible to practically everybody: to stockholders, large and small, to government, to workers, to customers, and to the public.

The continually enlightened attitude of the businessman toward activities previously considered extra-curricular for him should contribute much to that society of free men which we all wish to maintain.

We cherish our freedom; we cherish the rights inherent in that freedom; we set ourselves to all sorts of constructive activity resting upon those rights. But our very freedom entails obligations to be discharged. Those which I have touched upon tonight are intended simply as examples which mirror the spirit in which the sensitive business leaders of today and tomorrow will approach their responsibility to the public.

Planning A State-Wide Air Pollution Advisory Service

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Introduction

Whenever a visitor from either the eastern or midwestern section of the United States arrives in the state of Washington, his immediate reaction seems to be, "What do all of these people do for a living?" Obviously he considers us in the backwoods both geographically and industrially.

For years the industrial activities depended primarily upon the utilization of Washington's natural resources of which lumber, minerals, and coal were the most important ones. Communities sprang up around the various mills, mines, etc. Essentially these were single industry towns where the livelihood of virtually every person depended upon the industry.

Factors such as irrigation developments, cheap power through hydro-electric projects, better transportation facilities to Alaska and the Orient, and World War II defense projects have tended to increase industrial activities, particularly in the manufacturing line. Today most of the single-industry communities now have one or more additional types of industries. For example, since the war years a series of oil refineries, aluminum reduction and rolling plants, chemical plants, knitting mills, steel mills, metal manufacturing plants and innumerable others have started operating throughout Washington.

In order to illustrate the growth of communities in Washington the percentage increase of migratory population (1940-1950) for Tacoma, Washington, was 39.4%; for Los Angeles, California, it was 37.4%; for Seattle, Washington, it was 29.7%; for Spokane it was 23.4% and for Chattanooga it was 0.9%. To show that expansion of industry has kept pace with Washington's overall population growth of 37% (1940-1950), the per capita income of the state ranks within the top ten states.*

Development of Air Pollution Problems in Washington

In the single-industry communities where the livelihood of the people depended on the industry, little objection was voiced to air pollution. After all the smell of a pulp mill reminded the pulp mill worker of his income and in the same way dust from a cement plant reminded the cement worker of his income.

A few objections arose as the communities either became more diversified or pollutants affected other interests. There were cases of damage suits against smelters because pollutants (primarily SO_2 killed vegetation in the vicinity of the plants. The writer can recall the commotion caused in 1932 in a pulp mill town when the management of a hotel had the audacity to sue the pulp mill for damages caused by its effluent.

Another factor peculiar to the Northwest is the fact that for years wood was far cheaper for heating than coal even though fair amounts of a sub-bituminous coal were mined near Seattle. Because of this price differential, wood was an active competitor of coal particularly in residential heating. For this reason coal smoke from hand-fired furnaces remained at a minimum. Wood smoke has never caused the objections that coal smoke does. This can be illustrated if one considers how nice the odor of a campfire is to a camper!

About the time that Americans went in for automatic heat, wood began to be expensive in Washington, but by that time fuel oil, shipped by water from California, was at a competitive price level. Consequently residential heating went through a transition from primarily wood-fired to oil-fired. Of course some coal was and is still used.

Tacoma has for years had cheap hydroelectric power. As a result, diversification of industry in that area occurred earlier, and complaints of excessive air pollution were received for years. However, it was not until 1948 that a thorough study of air pollution was made in that city. Subsequently, a fairly good control ordinance was passed, but like many other cities insufficient funds were supplied for enforcement. As a result, the ordinance has not been effective. Currently the administration of this law is being revised and possibly an effective ordinance will result.

In the post-war years air pollution problems flooded the state. As examples, here are some of the major ones that have arisen:

> Continual complaints of corrosion and odor from pulp mill fumes are being received from every area where a pulp mill is operating.
>
> Bitter complaints of cinders are made mainly by housewives living near many of the lumber and plywood mills.
>
> Residents in orchard areas object to insecticides sprayed by aerial crop dusters on adjacent orchards.
>
> Wheat growers use herbicides to control weeds while grape growers in the vicinity complain that the herbicides kill their grapes.
>
> Dairymen near aluminum reduction plants claim that

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*"The Growingest Places—Should You Move?" *Changing Times*, pp 7-14, February, 1954.

fluorine cuts butterfat production and kills their cattle.

In addition of course, are the many and varied cases of air pollution that arise in every community.

What Laws Existed for Control of Air Pollution in the State of Washington?

On a state level, no laws exist for control of air pollution. However, the term "nuisance" is defined by statute in the State of Washington as follows:

> "Nuisance consists in unlawfully doing an act, or omitting to perform a duty, which act or omission either annoys, injures or endangers the comfort, repose, health or safety of others, offends decency, or unlawfully interferes with, obstructs or tends to obstruct, or render dangerous for passage, any lake or navigable river, bay, stream, canal, or basin, or any public park, square, street or highway; or in any way renders other persons insecure in life, or in the use of property.
>
> "The obstruction of any highway, or the closing of the channel of any stream used for boating or rafting logs, lumber, or timber, or whatever is injurious to health, or indecent, or offensive to the senses, or an obstruction to the free use of property, so as to essentially interfere with the comfortable enjoyment of life and property, is a nuisance, and the subject of an action for damages and other further relief."

Since air pollution is conceivably covered by this statute it is felt by many that either cities or air pollution districts do not require enabling acts in order to enact air pollution control laws.

The only general air pollution code in existence in the state is, as mentioned earlier, Tacoma's, which was patterned after the ASME model ordinance. Lack of finances to enforce the code has made it essentially ineffective.

In 1931 the Shelton city council passed this ordinance:

> "That the burning or disposal of refuse, sawdust, oil, fuel oil, or other material, in such a manner as to cause or permit ashes, sawdust, soot, cinders or other material to be cast upon the streets, and/or alleys of the City of Shelton or to cause or permit the smoke, ashes, soot, gases or other materials arising from such burning, to become annoying to any considerable number of persons or to damage the property of any considerable number of persons, or to injure or endanger the health, comfort or repose of said persons or to damage or injure the property of any person, or persons, firm, company or corporation, is hereby declared to be a nuisance."

A drive through this community will show that this ordinance has never been taken too seriously.

In 1938 the Seattle city council passed an ordinance specifying that the local gas company control its effluents. Today numerous complaints are being received concerning this same plant.

Apparently legal means of controlling air pollution exist in Washington, but quite obviously enforcement is not adequate.

In all fairness to the industries being accused of polluting the air virtually all of them are doing everything they can to control their problems. As an example, Kaiser Aluminum has spent $7,500,000.00 at their aluminum reduction plant near Spokane to install scrubbing towers in order to prevent emission of fluorides which is being blamed for killing the Ponderosa Pines found in that area. Unfortunately, there are always those who stall and do everything possible to avoid correcting a bad situation. It is here that adequate enforcement methods may be needed in addition to the State's existing laws.

Recent and Present Activities in Air Pollution

In 1949, Arthur E. Langlie, Governor of Washington, recognized the seriousness of the air pollution problem and requested the Pollution Control Commission, under the direction of Mr. E. F. Eldridge, to initiate a survey to secure facts concerning the problems of air pollution as they apply to the State. It was hoped that the information gathered by this survey would aid in avoiding or remedying the costly mistakes and complex problems created by air pollution.

The two major recommendations made in the report of this survey were:

> "Whereas air pollution problems in the State of Washington require combined judgment, highly technical assistance, and coordination of effort from the State level of the Government, it is recommended that the Governor appoint a State advisory committee on air pollution which shall include highly qualified representatives of industry, community and civic organizations, educational and research institutions, State agencies, and others concerned, for the purpose of evaluating facts on air pollution and making recommendations as to legislation, policy, or further action in the development of a State-wide air pollution program.
>
> "It is further recommended that the collection of information on air pollution, liaison between the groups concerned, technical assistance and encouragement, be continued at the State level."

The Washington State Institute of Technology at Washington State College in Pullman has maintained an active air pollution research unit. Their major projects have been concerned with the Ponderosa Pine tree blight and the effects of fluorides on cattle. In general, their main interests are in the agricultural aspects of air pollution.

In March 1951, the University of Washington, in line with its policy of extending its services for public use when they are not otherwise available, organized the Environmental Research Laboratory under the cooperative direction of allied departments in medicine, engineering, and meteorology. Applied research activities in occupational health and air pollution problems were consolidated in this laboratory.

Today the laboratory offers impartial consultation and laboratory services in occupational health and air pollution problems to industries and city, state, or national governmental agencies. All work is done on a fee basis as no state tax funds were allotted for operation of the laboratory. Currently, the research group is composed of three chemists, an industrial hygiene engineer, a pharmacologist, a mechanical engineer, a machinist, a secretary, and graduate students from engineering and medicine. Also, three physicians act as consultants.

As an indication of this group's scope of activities, here are some of the various types of requests and projects handled:

1. A year-long study of air pollution in Longview is being conducted under the sponsorship of local industries.
2. A similar study was conducted for Seattle and sponsored by the city.
3. A satisfactory method of measuring ozone in air pollution problems is being developed.
4. Assistance on methods of collecting wood cinders was requested by mill operators.
5. A two-year study concerning the effects of rocket exhaust gases on humans was conducted for the U.S. Air Force.
6. Assistance on dust control of asphalt plants near residential areas was requested by a county planning agent.
7. A county health officer requested assistance on determining the source of a syrup-like material which was being deposited over the community.
8. Numerous requests have been received for summaries of air pollution laws in other areas.
9. The King County Planning Commission requested technical advice on relocation of a foundry to Issaquah.
10. A county sanitarian requested assistance on incinerator design.
11. A study of cinder deposits in the Ballard area of Seattle was conducted.
12. Numerous items of information have been supplied to civic and industrial groups.
13. Requests to supply men trained in air pollution and industrial hygiene work have been received. In most cases it was not possible to assist.
14. Assistance has been requested by a city health officer concerning how to control the odor of feathers burned in a fertilizer manufacturing process used by an industry which plans to move to Washington.
15. A county planning agent requested assistance concerning air pollution control in oil refineries which were planning on locating in his area.
16. A county planning agent requested assistance on control of lead and zinc industries which are moving into his area.

By 1954, the staff of the laboratory was swamped with calls for information and assistance on air pollution problems. Many of these were processed as a public service, and as a result the laboratory's financial situation became critical, for the laboratory was expected to be completely self-supporting. Actually, air pollution problems in the state are not as critical as they would seem, but through the extensive publicity on air pollution in other areas, a growing awareness of it is found in Washington.

In order for the Environmental Research Laboratory to continue in this type of service, it was necessary that additional financial support be received. Consequently, the following cover letter and proposal for a statewide air pollution advisory service was sent to Governor Langlie.

"My dear Governor:

"Industrial expansion in the state of Washington coupled with over-emotional news and magazine articles concerning smog and smaze has prompted a growing awareness of local air pollution problems in many communities of the State.

"For the past three years, the Environmental Research Laboratory has attempted, as a public responsibility, to collect and disseminate factual information on air pollution. During the past few months the number of requests from planning commissions, health officials, civic officials and community groups for technical advice and assistance has increased to a point where adequate service cannot be given. Before the reason for this is discussed, I would like to briefly review the history of our laboratory.

"Approximately three years ago, at the time the State Health Department dropped its industrial hygiene activities, some members of the University staff recognized the need for continuation of a research group interested in occupational health and air pollution problems. Consequently, the Environmental Research Laboratory was organized. Financing of this group was to be done solely from research grants. Since that time, we have received numerous grants which restricted our research to certain specified problems. On this basis, we have managed to build a fairly complete staff and laboratory without using any state funds. Extensive studies of air pollution were conducted in Seattle, and currently a similar one is underway in Longview.

"Even though we have been confined to specifically defined work we needed to keep abreast of the rapidly developing technical developments in the air pollution field. Consequently, we have used every means possible to collect data on this subject. Because we are a state agency in name, many groups have turned to us for assistance, and wherever possible we have, for the sake of public relations assisted public groups by dissemination of this data and offering technical assistance.

"As a state group, we are expected to do much of this work as a courtesy. Many times a group such as a local health department or planning commission asks us for assistance. They have no funds available for our fees. What are we to do?

"If we insist on fees to cover our expenses, we create resentment toward the State government because we are identified with the state although not financially assisted in any way by it.

"If we supply a minimum of information and assistance, we cannot afford to follow through and see that it is used correctly. As an example, a county officer has asked us to supply him with multiple copies of material describing a sensational air pollution incident which can have no possible connection with his area. We feel that supplying him with factual material will be better than his collecting and disseminating the sensational material on this incident which has been published in popular magazines. This man desires to distribute the literature to local civic groups, etc. Unless adequate educational steps are taken, we fully expect an hysterical attack against a new large industrial plant which is to be constructed in this officer's area.

"Many more incidents can be cited.

"Since 1950, when the Pollution Control Commission reported to you concerning the status of air pollution in Washington, we have tried to fill in the needs outlined in their recommendations. We now find ourselves doing an inadequate service to the State. We are proud of our development, but extremely discouraged because we are forced to do only a half-way job.

"Consequently, the enclosed plan is being presented to you for your consideration."

"Very truly yours,
ROSS N. KUSIAN
Director"

Proposed Plan for a State-Wide Air Pollution Advisory Service

*I. "Introduction**

Until the last few years, air pollution was considered an index of America's prosperity and growth. Prospects were good where the factory chimneys smoked. That idea is rapidly becoming obsolete. Today people are realizing that unlimited release of waste products into the air has undesirable effects. This was called sharply to nation-wide attention by the fatalities in Donora in 1948, and has been kept in the public mind by the publicity given to the annoying smogs in Los Angeles, London, New York, and other cities.

"When people are troubled their reaction often is: 'There ought to be a law. . . .' Unfortunately, they are sometimes stirred up to demand one by crusaders who inject fear into their minds. So it is with air pollution. Reports of wild rumors about potential tragedies far worse than Donora have circulated in Washington communities when in actuality only minor air pollution problems have existed.

"Air pollution is not a serious or critical menace to public health. Scientific proof of relationsip between air contaminants and damage to health remains inconclusive. However, there is no doubt that in many communities air pollution is a nuisance—a very real one. Smoke and other varieties of contaminants soil laundry, wall paper, curtains, parked automobiles, etc., and certain odors are objectionable. Also, instances of direct property damage, such as premature failure of paint and damage to plant and animal life occur.

"In many Washington communities air pollution laws are being considered. The first consideration should be toward whether a new law is needed. Efforts should be directed toward full utilization of existing legislation on nuisances. The second consideration should be toward the establishment of a good control law only when other methods have failed.

"The Los Angeles situation is a stern warning of what can happen when controls are hastily instituted without adequate technical knowledge. By law the machinery for air pollution control was created and set in motion. Before knowing the reason for the smog's undesirable effects, arbitrary rules and regulations were decreed. In less than two years 12 million dollars were spent within Los Angeles County for the reduction and control of air pollution—all without knowledge of what to correct! It is not surprising that even this large sum did not effect a cure.

"By cooperatively working with local officials and industries is it not possible that an advisory or consultant group composed of experienced chemists, engineers, physicians, and meteorologists could utilize the technical know-how learned from other areas in solving, within the existing framework of legislation, the air pollution problems of Washington?

*II. Fundamental Precepts**

"*Air is a useful natural resource.* Since the beginning of life on this planet the atmosphere has functioned as an acceptor of emitted wastes. Breathing creatures inhale oxygen and exhale carbon dioxide, which is transferred through the air to green vegetation where the oxygen is released to complete the cycle. As industrial activities developed, there was no reason to question releasing waste products into the air—not until the amount became 'too much.'

"The objective of air pollution control should be to limit the amount of foreign material in the air so that there will not be 'Too much' but at the same time allow the atmosphere to function usefully to its full capacity. This principle is recognized in the Oregon air pollution bill.

"Superficial consideration of how much air pollution is 'too much' occasionally leads people to the faliacious view that the remedy is to establish concentration limits for each air contaminant at the source of emission, and apply them uniformly throughout the state or nation. This is wrong, both technically and economically, for it would require everyone to meet the restrictions required for the worst situation. Specific concentration values become significant only when used in conjunction with such factors as rate of emission, stack height, meteorological conditions, topography, effect at point of contact, etc.

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*This material taken in part from *A Rational Approach to Air Pollution Legislation* published by Manuf. Chem. Assoc., Inc.

"On the basis of these precepts the following principles should act as a guide to air pollution activities: Technical advice and assistance should be available to communities and industries in order to assist in prevention of the pollution of atmosphere to the detriment of health and property. Air pollution control should not be construed as contrary to the reasonable or natural use of air for dispersing waste products within the proper capacity to do so. Each localized area, i.e., affected by the same sources of pollution, shall be considered unique, and pollution within the area judged on the basis of its specific effects. Suggested modifications for pollution reduction and control shall remain within the bounds of scientific knowledge and economic feasibility. The responsibility for proper control of emission shall lie with the potential offender and the local community.

III. Organization

"Air pollution is strictly a localized problem, unique to the particular locality and to the economy of the community. However, in view of its technical complexity, the cost of adequate physical facilities for dealing with it from an investigative point of view is so great that these facilities would be prohibitively expensive for all but a few heavily populated centers. Therefore, as a matter of principle, it is impractical to consider establishing independent air pollution groups exclusively at the local level. It follows logically, that the proper place to establish technical facilities for measuring air pollution and appraising its effects is within an agency of the state government.

"The suggested organization of an air pollution advisory service is:

"1. The Director of the Washington Pollution Control Commission would be the state official cognizant of all air pollution activities.

"2. The staff of the Environmental Research Laboratory would act as technical consultants on air pollution problems affecting the health and welfare of the community.

Because of the cooperative medical-engineering administration of this research group, the vast technical facilities of all of the University is available in case of a special problem.

"Because duplication of an organization such as this would be extremely costly, use of the Environmental Research Laboratory seems to be the most logical and economical means of meeting the air pollution problem. Also, this arrangement would offer an opportunity for practical experience to students who need training in the rapidly expanding field of air pollution engineering.

"Problems concerning effects of air pollution on animal life and vegetation would continue at the Washington Institute of Technology.

"3. A voluntary committee composed of state-wide leaders of industry, civic officials, and educational representatives would serve as a general policy making group. In actuality, such a group exists in the Washington State Health Council's air pollution committee. This committee, which has been meeting voluntarily for the past two years, is composed of members from the following groups:

Washington State Medical Association
Pulp and paper industry
Aluminum industry
Association of Washington Cities
Cement industry
Washington State Aeronautics Commission
Washington State Department of Health
University of Washington
Washington State College
Railroad industry

The opinions of this group have been an unofficial guide to the activities of the Environmental Research Laboratory.

IV. Duties of the Advisory Service

"1. Assemble and distribute objective and technical information concerning air pollution and its control.

"2. When requested, meet with community and industrial representatives concerning advice and assistance on methods of control, extent of problem, effect on health, etc.

"3. Consult and cooperate with all other agencies in furthering the objective of reasonable air pollution control.

"4. Conduct limited field studies in necessary cases. If extended studies are required, the community and industry involved should carry a portion of the cost."

The budget in this proposal allows for an engineer, and a chemist or meteorologist at one-half time each; a full-time secretary who would handle literature collection; and a graduate student. While this is a very modest start, it was felt that a good basic program can be developed.

On March 15, 1954, Governor Langlie approved this plan and appropriated the requested amount from his emergency funds. Because this paper was written on this date further developments in this advisory service will have to be reported at some other time. However, it is expected that the Air Pollution Control Association will be a prime source of information, assistance, and advice.

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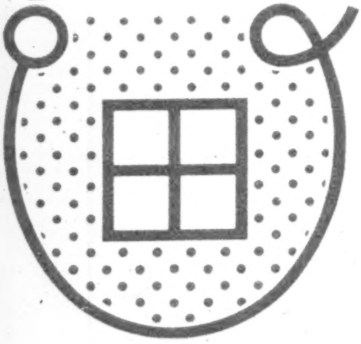4400 FIFTH AVENUE - PITTSBURGH 13, PA.